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Spaceborne Ocean Intelligence Network

SOIN - fiscal year 08/09 year-end summary

Darryl Williams, Paris W. Vachon, John Wolfe, Michael Robson,
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Defence R&D Canada – Ottawa

Canada

External Client Report
DRDC Ottawa ECR 2009-139
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This document is the SOIN project FY2008/09 annual report to the Canadian Space Agency's Government Related Initiatives Program.

Abstract

SOIN is a five-year research and operational development initiative that addresses barriers to implementing certain oceanographic applications of the Earth-observation sensors RADARSAT, AVHRR, MERIS and MODIS. The project is divided into two phases with the first three-year phase focusing on developing state-of-the-art sea-surface temperature and diver-visibility products, operational tools, supporting infrastructure and the ability to detect thermal fronts, eddies and water mass boundaries with RADARSAT. The project began in June 2007 with funding provided by the Canadian Space Agency through its Government Related Initiatives Program. This report provides a summary of project activities and accomplishments in FY 08/09 and insight into its objectives for FY 09/10.

Résumé

Le Réseau spatial de renseignement sur l'océan (RSRO) est une initiative quinquennale de recherche et développement opérationnel visant à lever les obstacles à la mise en oeuvre de certaines applications en océanographie des capteurs d'observation de la Terre RADARSAT, AVHRR, MERIS et MODIS. Le projet comprend deux phases dont la première, d'une durée de trois ans, est centrée sur le développement de produits à la fine pointe de la technologie dans les domaines suivants : température de la surface de la mer et visibilité des plongeurs, outils opérationnels, infrastructure de soutien et capacité de détecter les fronts thermiques, les tourbillons et les limites entres masses d'eau au moyen du RADARSAT. Le projet a été lancé en juin 2007 grâce au financement fourni par l'Agence spatiale canadienne dans le cadre de son Programme des initiatives gouvernementales. Le présent rapport fournit un résumé des activités menées pour le projet et des résultats obtenus pendant l'exercice financier 2008/2009 ainsi qu'un aperçu des objectifs pour l'exercice 2009/2010.

Executive summary

Spaceborne Ocean Intelligence Network: SOIN - fiscal year 08/09 year-end summary

Williams, D.; Vachon, P.W.; Wolfe, J.; Robson, M.; Renaud, W.; Perrie, W.; Osler, J.; Isenor, A.W.; Larouche, P.; Jones, C.; DRDC Ottawa ECR 2009-139; Defence R&D Canada – Ottawa; September 2009.

Introduction: SOIN (Spaceborne Ocean Intelligence Network) began in June 2007 with funding provided by the Canadian Space Agency through its Government Related Initiatives Program. Lead by MetOc Halifax, it is a five-year research and operational development initiative that addresses barriers to implementing certain oceanographic applications of Earth-observation sensors. The project focuses on developing state-of-the-art sea-surface temperature and diver-visibility products, operational tools, supporting infrastructure and the ability to detect thermal fronts, eddies and water mass boundaries with RADARSAT. SOIN's primary operational user will be the Canadian Forces. This report provides a summary of project activities and accomplishments in FY 08/09 and insight into its objectives for FY 09/10.

Results: SOIN continued work on three work packages in FY 08/09: work package (WP) 2 (Automatic Processing System (APS)), WP 3 (SAR processor, Image Analyst Pro (IA Pro) and Commercial Satellite Imagery Acquisition Planning System (CSIAPS)) and WP 4 (Ocean features from synthetic aperture radar (SAR)). WP 2 is complete except for the implementation of MERIS data and the connection of MetOc Halifax's X-band receiver for MODIS data reception, activities dependent on outside factors beyond the project's control. WP 3 is complete except for ongoing support and required modifications to the IA Pro and CSIAPS software as other WPs develop. WP 4 is in progress and research continues on the detection of both ocean and atmospheric features of SAR imagery. Work commenced on WP 5 (MetOc Halifax ocean workstation (OWS) compatibility) in FY 08/09. Also, two new work packages were created: WP 7 (SAR Ocean Imaging Model) and WP 8 (Statistical Analysis of RADARSAT-2 data). It was decided to defer WP 7 until Phase II of the project. WP 8 was initiated in August 2008, and has provided routines and improvements to features in IA Pro.

In FY 09/10, SOIN will focus on three WPs: WP 4 (developing the ability to detect ocean features with RADARSAT, for operational purposes), WP 5 (integrating SOIN's infrastructure into MetOc Halifax operations by developing a SOIN-compatible version of MetOc Halifax's Ocean Workstation (OWS)), and WP 8 (statistical analysis of RADARSAT-2 data). WP 6 (Go/No Go decision) will be initiated at a workshop to be held in December 2009 at MetOc Halifax.

Significance: The SOIN project has achieved its FY 08/09 objectives and is on schedule to fulfill its FY 09/10 objectives.

Future plans: The SOIN project will continue to be implemented over its remaining three year period as per the project plan provided in Annex A of this report. The results of WP 6 will provide a report and recommendations on the feasibility of continuing the SOIN project for a further two years, and will be delivered to the CSA in early 2010 for a decision.

Sommaire

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Introduction : Le RSRO (Réseau spatial de renseignement sur l'océan) a été lancé en juin 2007 grâce au financement fourni par l'Agence spatiale canadienne dans le cadre de son Programme des initiatives gouvernementales. Dirigée par le MetOc de Halifax, cette initiative quinquennale de recherche et développement opérationnel vise à lever les obstacles à la mise en oeuvre de certaines applications en océanographie de capteurs d'observation de la Terre. Le projet est centré sur le développement de produits à la fine pointe de la technologie dans les domaines suivants : température de la surface de la mer et visibilité des plongeurs, outils opérationnels, infrastructure de soutien et capacité de détecter les fronts thermiques, les tourbillons et les limites entres masses d'eau au moyen du RADARSAT. Les Forces canadiennes seront le principal utilisateur opérationnel du RSRO. Le présent rapport fournit un résumé des activités menées pour le projet et des résultats obtenus pendant l'exercice financier 2008/2009 ainsi qu'un aperçu des objectifs pour l'exercice 2009/2010.

Résultats : Au cours de l’exercice 2008/2009, le RSRO a poursuivi ses travaux sur trois blocs de tâches, soit le (BT) 2 (APS : système de traitement automatique), le BT 3 (processeur RSO, IA Pro [Image Analyst Pro] et SPAISC [Système de planification d'acquisition d'images de satellites commerciaux]) et le BT 4 (Entités océaniques d'après les images RSO). Le BT 2 est terminé à l’exception de la mise en oeuvre des données MERIS et de la connexion du récepteur en bande X du MetOc de Halifax pour la réception des données MODIS, activités qui dépendent de facteurs externes hors du contrôle du projet. Le BT 3 est terminé à l’exception du soutien permanent et des modifications à apporter aux logiciels IA Pro et SPAISC avec la mise en place d’autres BT. Le BT 4 progresse et les recherches se poursuivent en ce qui concerne la détection des caractéristiques océaniques et atmosphériques de l’imagerie ROS. Les travaux du BT 5 (compatibilité du poste de travail océanique [OWS] du MetOc de Halifax) ont débuté au cours de l’exercice 2008/2009. En outre, deux nouveaux blocs de tâches ont été créés : le BT 7 (modèle d’imagerie océanique ROS) et le BT 8 (analyse statistique des données de RADARSAT 2). On a décidé de reporter le BT 7 à la phase II du projet. Le BT 8 a débuté en août 2008 et progresse; il a permis d’établir des routines et d’apporter des améliorations aux caractéristiques d’IA Pro.

Au cours de l’exercice 2009/2010, les travaux du RSRO se concentreront sur trois BT : le BT 4 (développer à des fins opérationnelles l'aptitude à détecter des entités océaniques avec le RADARSAT), le BT 5 (intégrer l'infrastructure du RSRO aux opérations du MetOc de Halifax en développant une version du poste de travail océanique [OWS] du MetOc de Halifax compatible avec le RSRO), et le BT 8 (analyse statistique des données de RADARSAT 2). Le BT 6 (décision de poursuivre ou non le projet) sera lancé lors d’un atelier prévu pour décembre 2009 au MetOc de Halifax.

Importance : Les objectifs du projet RSRO pour l'exercice 2008/2009 ont été atteints et l'atteinte de ceux pour l'exercice 2009/2010 respecte les échéanciers.

Perspectives : La mise en oeuvre du projet RSRO se poursuivra conformément au plan fourni à l'annexe A du présent rapport pendant les trois années qui restent à écouler de sa durée prévue de cinq ans. Les résultats du BT 6 feront l’objet d’un rapport et de recommandations touchant la faisabilité de poursuivre le projet RSRO pendant deux autres années, qui seront présentés à l’ASC au début de 2010 aux fins d’une décision

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Acknowledgments

We thank the following individuals for their contributions to the success of the SOIN project: Brendan DeTracey (DFO/BIO); Tao Xie and Biao Zhang (NSERC Visiting Fellows at DFO/BIO); Audrey Patry-Quintin (DFO/IML); Doug Vandemark (University of New Hampshire); and Todd Sikora (Millersville University).

1 Introduction

SOIN (Spaceborne Ocean Intelligence Network) is a five-year research and operational development initiative that addresses barriers to implementing certain oceanographic applications of the Earth-observation sensors RADARSAT, AVHRR, MERIS and MODIS [1]. The project is divided into two phases with the first three-year phase focusing on developing state-of-the-art sea-surface temperature and diver-visibility products, operational tools, supporting infrastructure and the ability to detect thermal fronts, eddies and water mass boundaries with RADARSAT. This report provides a summary of project activities and accomplishments in FY 08/09 and insight into its objectives for FY 09/10.

Lead by MetOc Halifax, SOIN was launched in June 2007 with funding provided by the Canadian Space Agency (CSA) through its Government Related Initiatives Program (GRIP). GRIP is providing 30% of SOIN's phase one financing, with the remaining resources being provided by MetOc Halifax, DRDC Ottawa and Atlantic, the Canadian Ice Service (CIS) and the Department of Fisheries and Oceans (DFO).

Three fundamental barriers that SOIN must address in order to achieve its operational objectives are: (i) a lack of required infrastructure; (ii) insufficient auxiliary data provided in required time frames, spatial scales and file formats; and (iii) insufficient knowledge of how to interpret synthetic aperture radar (SAR) imagery for operational ocean feature applications [1].

SOIN's primary operational user will be the Canadian Forces (CF), with MetOc Halifax as the lead agency. The CIS, Ottawa, and the Joint Rescue Coordination Centre (JRCC), Halifax, are also potential users of SOIN's infrastructure and products.

This GRIP-funded project was initiated in June 2007. Its objectives, work packages, milestones, deliverables and due dates were identified in last year's annual report [18].

In FY 08/09, several project meetings were held, including the synthetic aperture radar (SAR) field program meeting in Halifax (14 July 2008), an IA Pro/SAR ordering meeting in Ottawa (16 July 2008), and a SOIN mid-year project update meeting held at MetOc Halifax (3-4 December 2008). Project members attended two Earth Observation Marine Security Coordination Committee (EOMSCC) meetings, in Montreal (17-18 June 2008) and in Ottawa (19 March 2009). Conferences attended by SOIN members included the International Geoscience and Remote Sensing Symposium (IGARRS) in Boston (7-11 July 2008) and the CSA RADARSAT-2 Workshop in St Hubert (16-18 September 2008).

The purpose of this External Client Report (ECR) is to summarize SOIN's second year (FY 08/09) accomplishments and to outline plans for the next fiscal year (FY 09/10). This information is provided in detail in Section 2 and is summarized in Section 3.

2 Work packages

As identified in Annex A, in addition to project management tasks, in FY 08/09 work continued on three work packages (WPs 2, 3, 4), and was initiated on WP5 and the newly created WP 8. WP 6 is scheduled to begin in FY 09/10. WP 7 has been deferred until Phase II of the project.

2.1 WP 2. Automated Processing System

2.1.1 Work tasks

The purpose of WP 2 is to acquire, install, upgrade and integrate the U.S. Navy's Automated Processing System (APS) into MetOc Halifax operations. APS automatically ingests spaceborne thermal IR and multispectral data and produces thermal and water-visibility products required for purposes pertaining to maritime defence and homeland security. The overall expected result of this WP is to have a Canadian version of APS integrated into MetOc Halifax operations by the end of Phase 1 (comprising the first three years of SOIN). WP 2 comprises the following tasks:

WP 2.1 – Hire MetOc Halifax programmer;

WP 2.2 – Purchase and install APS hardware;

WP 2.3 – Staff training on APS;

WP 2.4 – Install APS at MetOc Halifax;

WP 2.5 – Connect MetOc Halifax L-band dish (for AVHRR data reception) to APS;

WP 2.6 – Assess standard APS Sea-Surface Temperature (SST) product suite to meet client needs – modify as required;

WP 2.7 – Import MERIS and MODIS offline data and assess resulting APS products;

WP 2.8 – Connect MetOc Halifax X-band dish (for MODIS data reception) to APS.

2.1.2 Progress in FY 08/09

WPs 2.1-2.5 Status: completed

WP 2.6 Status: completed

DFO/Institute Maurice Lamontagne (IML) completed an assessment of APS products by comparing them to DFO-generated SST products; an example is shown in Figure 1 through Figure 3. The types of APS products tested were latest pixel composite (LPC) and mean composite (MC). In general, APS MC calculated temperatures are slightly higher than DFO's. For edge detection, APS MC products present similar results to DFO-generated products. APS

LPC products were not recommended to be used for generating high quality, high level products. The biggest problem encountered with both APS and DFO products is cloud detection. The study indicated that efforts should be made towards the development of a better cloud masking capacity in the APS system.

WP 2.7 Status: in progress

MERIS data acquisition was accomplished via download from the Canada Centre for Remote Sensing (CCRS) ftp site. MetOc Halifax received an APS software patch from the Naval Research Laboratory, Stennis in late March 2009 that fixed a processing problem and enabled MERIS processing. MetOc Halifax installed a new MODIS processing workstation in November 2008 as part of a lifecycle systems upgrade.

WP 2.8 Status: in progress

The Polar Epsilon project funded X-band satellite receiving antenna for MetOc Halifax has experienced delays. The antenna is now scheduled to be installed in May 2010.

2.1.3 Plans for FY 09/10

MetOc Halifax is now processing downloaded MERIS data. Diver visibility and chlorophyll products will be generated by APS using downloaded MODIS and MERIS data. To solve the problem of cloud masking, the project will integrate an additional step in its processor in the form of a climatological filter provided by IML that will generate better SST products. Preliminary results from the climatological filter clearly show the advantages of such an approach.

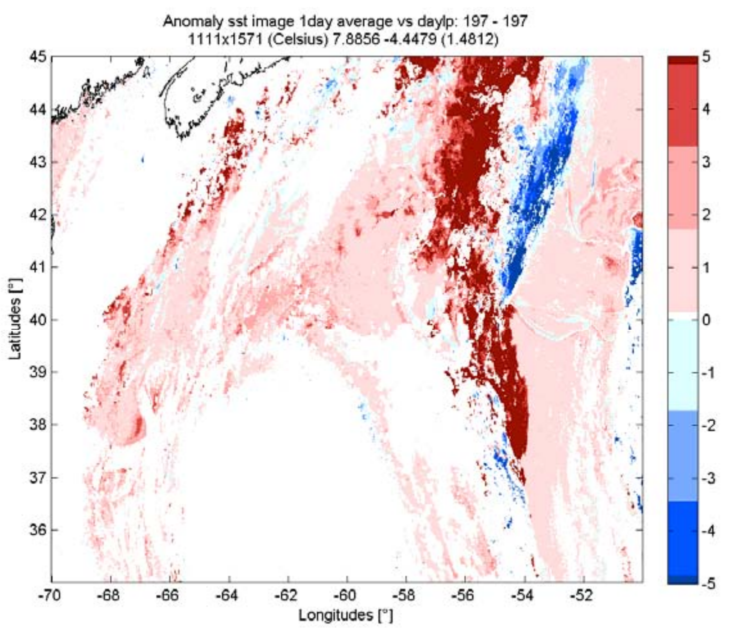

Figure 1: 15 July 2008 anomaly of APS 1-day latest pixel SST vs. DFO SST average pixel.

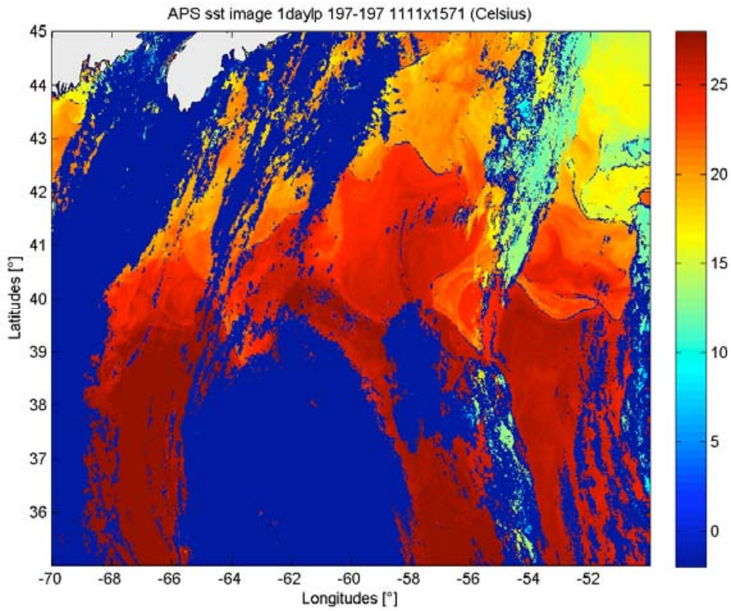

Figure 2: 15 July 2008 APS 1-day latest pixel.

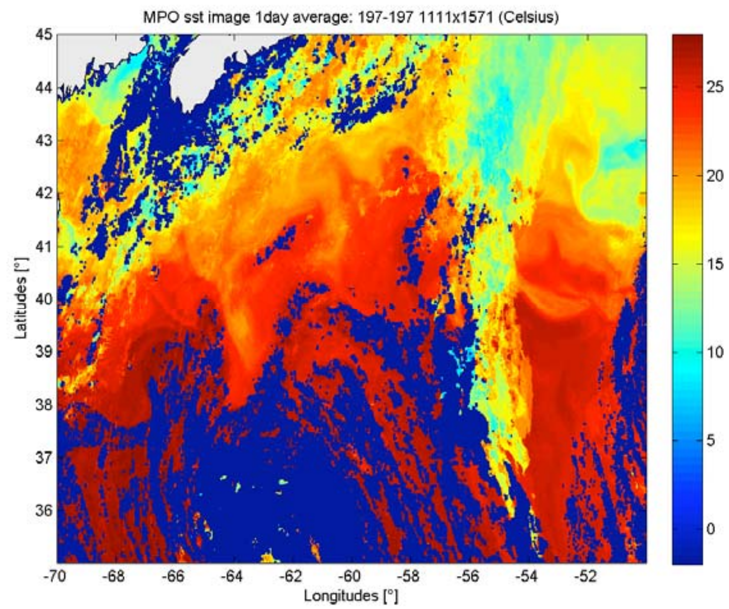

Figure 3: 15 July 2008 DFO SST average pixel.

2.2 WP 3. SAR processor, IA Pro and CSIAPS

2.2.1 Work tasks

The purpose of WP 3 is to develop, build and install a MetOc SAR processor, and to modify Image Analyst Pro (IA Pro) and the Commercial Satellite Imagery Acquisition Planning System (CSIAPS) to produce MetOc-specific versions of these tools, which were developed by DRDC Ottawa. IA Pro is a test bed and demonstration tool that assists in the visual interpretation of remote sensing imagery. It provides capabilities to overlay multiple imagery sources and to locate and visualize target information. CSIAPS includes an imagery archive component. The overall expected result of this work package was to have a MetOc-specific SAR processor / IA Pro and CSIAPS system integrated into MetOc Halifax operations by the end of SOIN Phase 1. WP 3 comprises the following tasks:

WP 3.1 – Develop approach;

WP 3.2 – Hire contractors and assign DRDC Ottawa staff;

WP 3.3 – Recommend hardware for purchase by MetOc Halifax;

WP 3.4 – Develop SAR automatic processor V1.0 & install at MetOc Halifax;

WP 3.5 – Upgrade/modify and install IA Pro and CSIAPS data archive at MetOc Halifax;

WP 3.6 – Produce shapefiles of bathymetric contours at depths of 30, 50, 100, 200, 500, 1000, 2000 metres;

WP 3.7 – Interim status reviews for SAR-related work (WP 3 & 4);

WP 3.8 – Develop specifications for the MetOc Halifax version of IA Pro;

WP 3.9 – Evaluate RADARSAT-2 data within MetOc SAR processor;

WP 3.10 – Develop interim and final versions of MetOc-specific version of IA Pro;

In 2008/2009, work focused on WP 3.7, 3.8, 3.9, and 3.10, as described below. All work packages are now complete, aside from WP 3.10.

2.2.2 Progress in FY 08/09

WP 3.1-3.8 Status: completed

WP 3.9 Status: completed

Extensive upgrades to the IA Pro and CSIAPS software tools were completed and delivered to SOIN, as outlined below.

2.2.2.1 Upgrades to Image Analyst Pro

IA Pro has continued to evolve and be improved to support SOIN requirements. SOIN-specific IA Pro developments are discussed below. All SOIN functional capabilities are now integrated into the general IA Pro development stream. As such, IA Pro improvements made for other projects are also available to SOIN users. IA Pro Version 1.9, which is available for Windows, Linux, and Solaris, was provided to SOIN in March 2009 as a major DRDC Ottawa deliverable.

(i) SAR Ocean Feature Detection Tool (SOFDT). The system was extended to support RADARSAT-2 products. At the request of BIO, new outputs from the system include the gradient of the derived wind speed (Figure 4), the curl (Figure 5) and divergence (Figure 6) of the derived wind field. The source of the input wind directions has also been extended (from QuikSCAT) to include wind direction gridded binary (GRIB) data from regional forecasts, and a simple ASCII format. The wind direction interpolation scheme was also updated to improve the output quality. To eliminate bias in derived wind speeds, a pre-pass median-filter was implemented to detect and remove undesirable targets such as ships, replacing them with the local median (see Figure 7 and Figure 8).

(ii) Toggle Look-Up Table. SST images are single-band data representing sea-surface temperatures. Many SST images have look-up tables (LUTs) that enable the user to view the image in a colourized view. However, in many cases, IA Pro operators may wish to revert from the colourized view to the greyscale view of the data. These SST LUTs can now be turned on or off simply by opening a colourized SST image in IA Pro, then selecting the 'Revert to No Enhancement' function, indicated by the  icon. Repeatedly selecting this icon causes the SST image to toggle between greyscale and colourized views.

(iii) Calibrated Greyscale Gradients from Colourized Images, and Gradient Scale-bar. SST images that contain LUTs are opened in IA Pro in a colourized view. Since they are single-band images, the greyscale data are transformed to digital numbers representing the display colours. In the implementation of the SST gradient calculations, the colourization was causing the calibration of the temperature gradients to become meaningless because the digital numbers represented colours, not temperatures. In a modification to the gradient processor, the LUT is now detected and the gradient processor does a reverse transformation through the LUT to change the digital numbers to temperatures. The net effect of this is that processing the SST images through the SST Gradient capability in IA Pro now results in a calibrated output for both colourized and non-colourized SST products (Figure 9). A companion capability to this implementation was added to provide a scale-bar to display the calibrated gradient scale in IA Pro (Figure 10). This scale-bar is added as a raster layer and loaded to IA Pro at the same time as the gradient.

(iv) Display the Platform Heading and Sensor Look Direction. For RADARSAT-1 and RADARSAT-2 data, visual guides can now be displayed in IA Pro that indicate the direction of the platform heading and the sensor look direction relative to the edge of the image. This capability causes arrows to be drawn that indicate the direction along which the platform progressed as the image was acquired (the platform heading, or the azimuth direction) and the direction along one of the image edges in which the range increases (the sensor look direction, or the range direction). The platform heading direction is indicated by an A (for Azimuth) and the range direction is indicated by an R (for Range) near the respective arrow heads. This function causes two vector layers to be activated, one for the azimuth reference line and label, and one for

the range reference line and label. An example is shown in Figure 11. By design, this capability only draws the lines at the image boundaries. If the user zooms to a region in the image in which the image boundaries are not visible, they will be unable to see either reference line.

(v) Display Digital Numbers, Sigma Nought and Incidence Angle. For every image that is opened in IA Pro, the bottom part of the main window now displays the Digital Number, Sigma-Nought and Incidence Angle. These displays are updated automatically to the current pixel in the image as the user moves the cursor across the image. An example is shown in Figure 12. The display works as follows:

- Digital Number (DN)
    - Displays the raw digital number as stored in the image file for the current pixel; Complex data are converted to digital numbers before being displayed;
    - If the cursor is off the image, the display reads 'No Data';
    - If the image only has one band, only one number appears;
    - If the image has two bands, the DNs for the two bands are displayed with their IA Pro colour assignment (r, g, or b). If a band is assigned to two colours, then two of r, g, or b are displayed next to the DN. If a band is assigned to all three colours, then 'rgb' is displayed next to the DN, and the DN for the other band is not displayed;
    - If the image has more than two bands, then a DN is displayed for each r, g and b colour assignment, even if they are the same band.
- Sigma-Nought
    - Only works for RADARSAT-1 and RADARSAT-2 data with appropriate headers, otherwise, the display reads 'No Data';
    - If the cursor is off the image, the display reads 'No Data';
    - The Sigma-nought value is computed in real time and displayed in dB for the current pixel;
    - For each band in the DN display, sigma-nought is displayed in the same order.
- Incidence Angle
    - Only works for RADARSAT-1 and RADARSAT-2 data with appropriate headers, otherwise, the display reads 'No Data';
    - If the cursor is off the image, the display reads 'No Data';
    - The incidence angle for the current pixel is computed in real time and displayed in IA Pro.

(vi) Other IA Pro Enhancements. Various minor enhancements have been added to IA Pro for SOIN purposes, as follows:

- Modified SST contouring to calculate and display contours for temperatures down to 0 degrees Celsius;
- In the image crop capability: ungeoreferenced images can now be cropped in the correct location; LUTs from the original image are now preserved in the cropped image;

- The mensuration tool now displays both the distance and heading between points;
- On line documentation has been introduced and improved;
- Other bug fixes and support issues, as and when required.

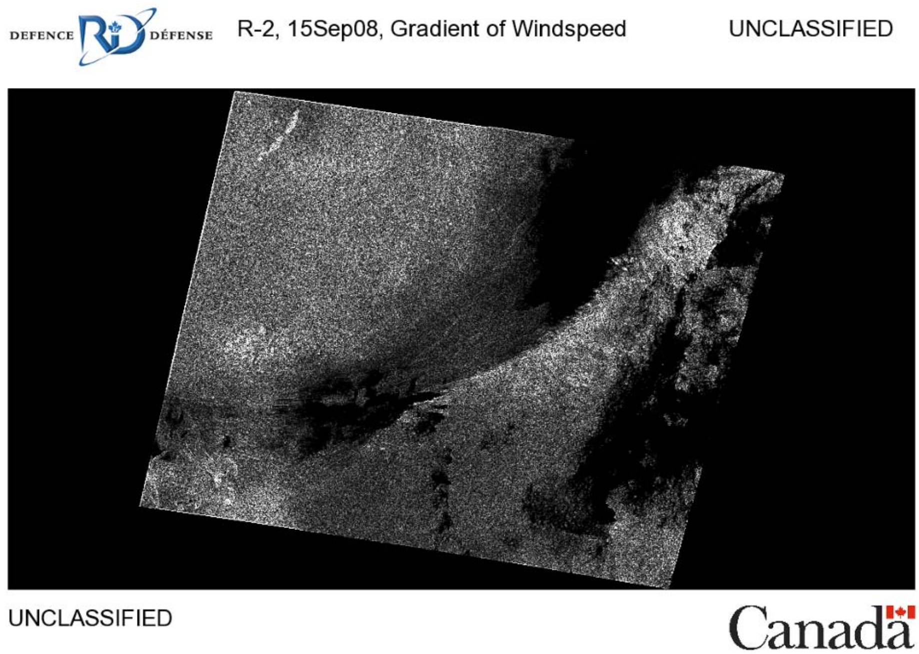

Figure 4: Gradient of wind speed, RADARSAT-2, SCNA, 15 September 2008.

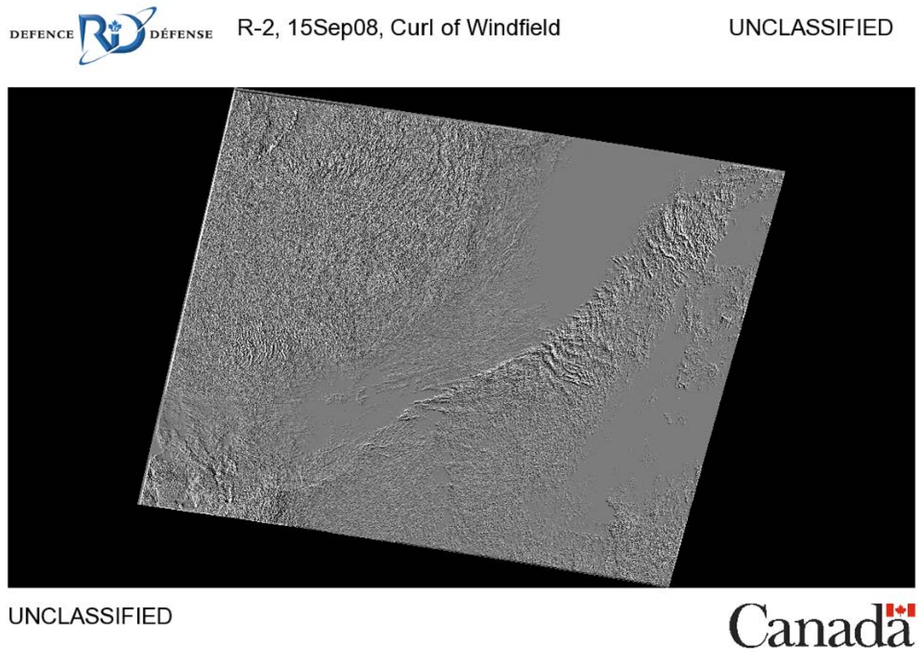

Figure 5: Curl of wind field, RADARSAT-2, SCNA, 15 September 2008.

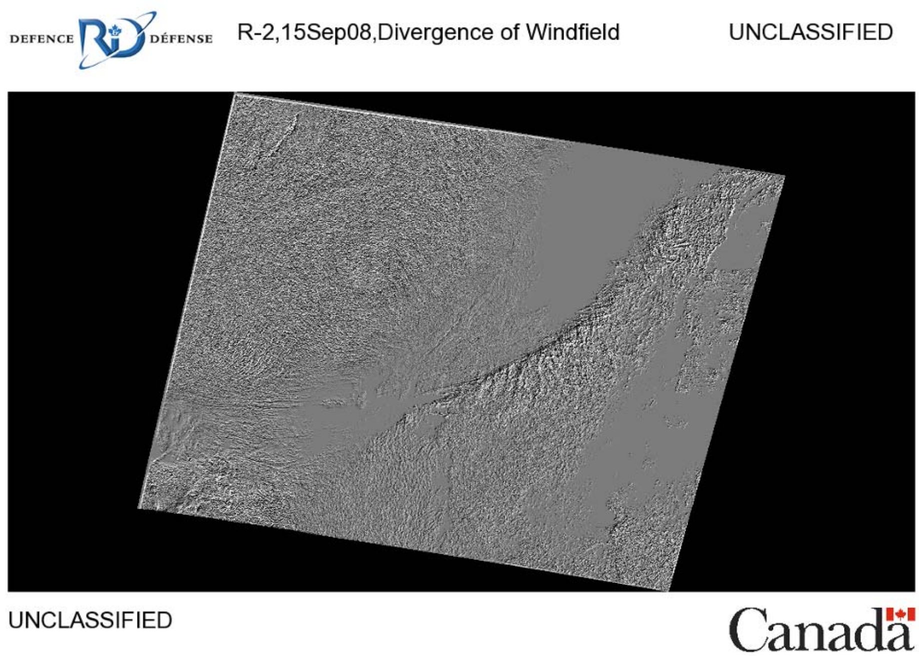

Figure 6: Divergence of wind field, RADARSAT-2, SCNA, 15 September 2008.

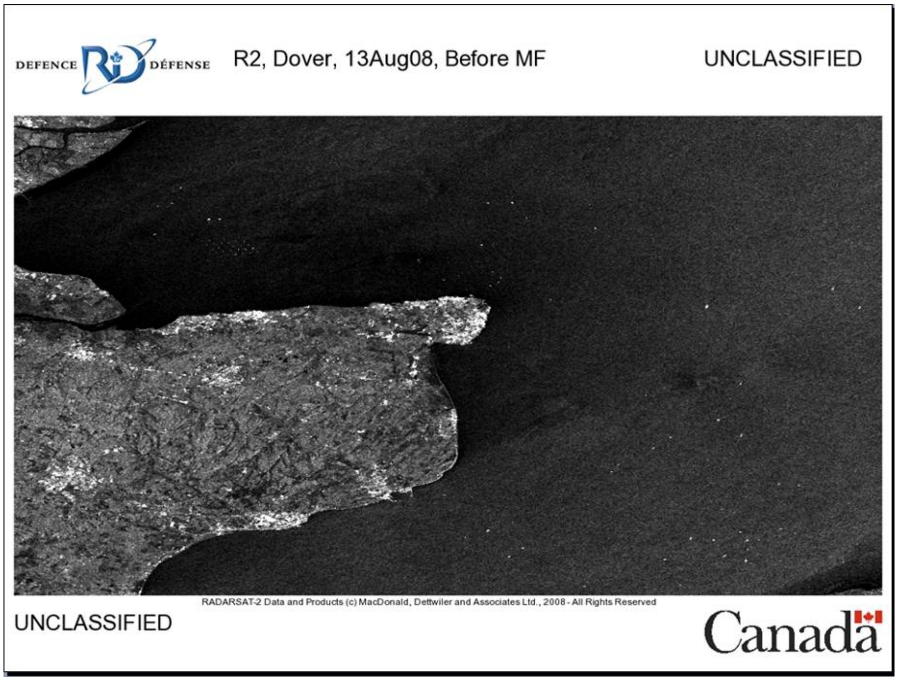

Figure 7: Before Median Filter, RADARSAT-2, SCNA, 15 September 2008.

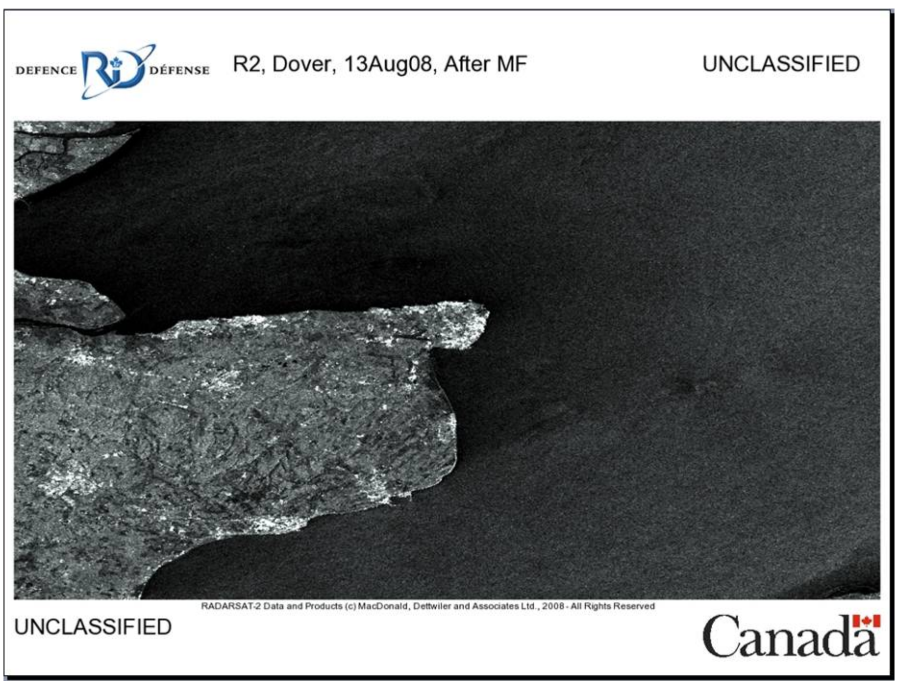

Figure 8: After Median-Filter, RADARSAT-2, SCNA, 15 September 2008.

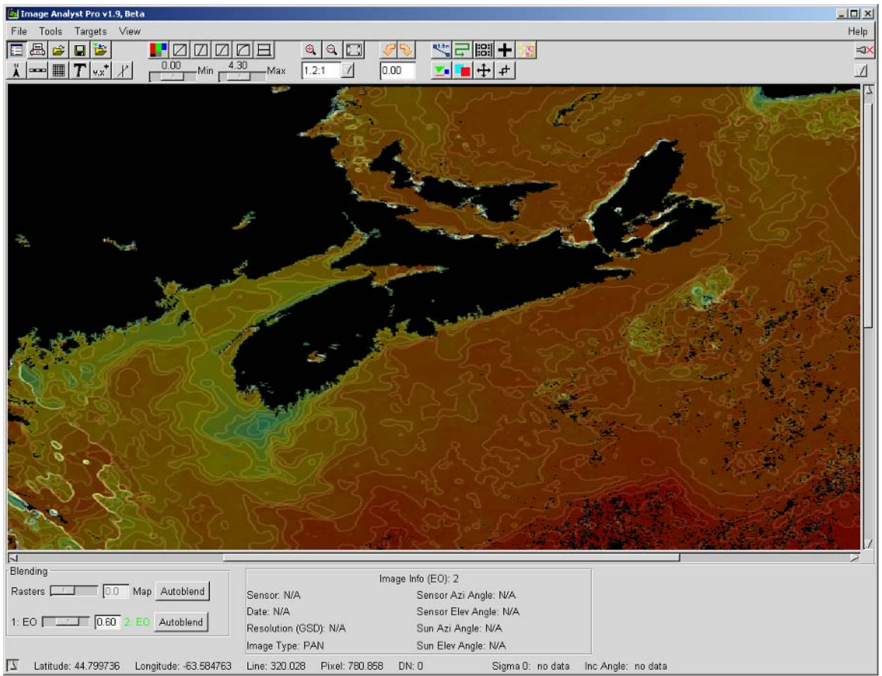

Figure 9: Colourized SST field and embedded SST gradient.

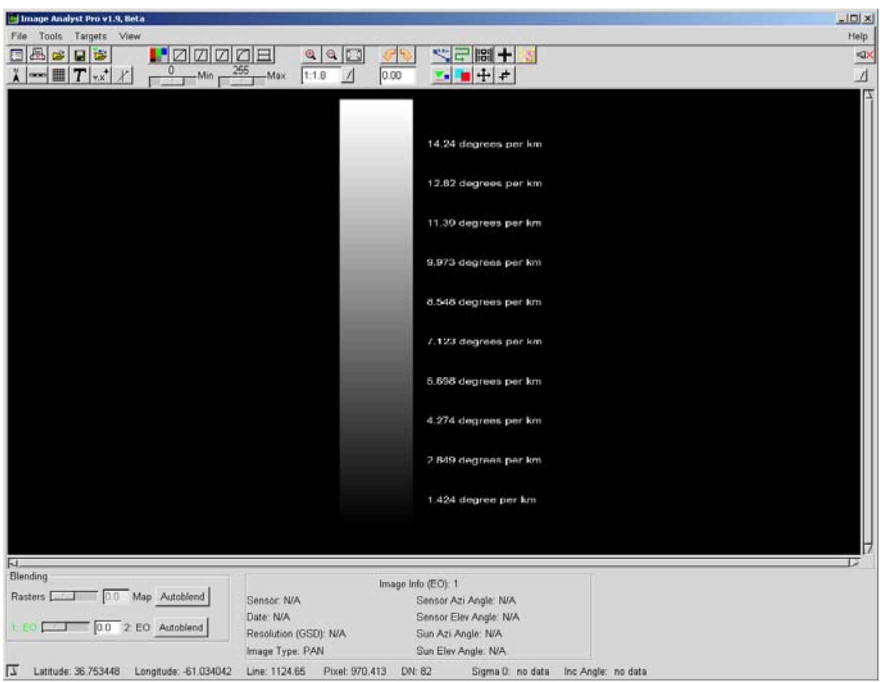

Figure 10: The accompanying legend for the SST gradient of Figure 9.

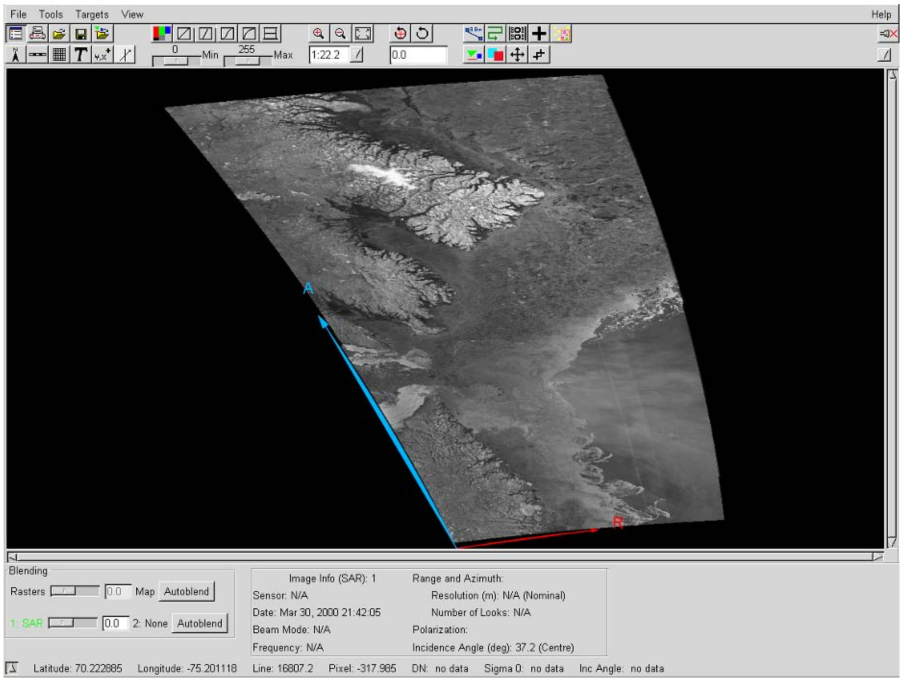

Figure 11: RADARSAT-2 SAR image with Range (R) and Azimuth (A) indicated.

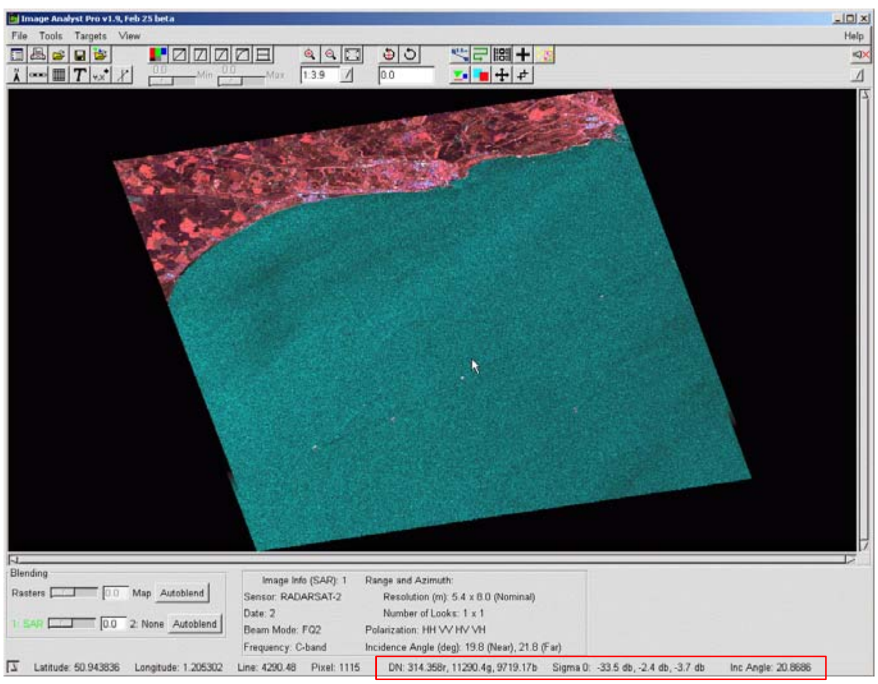

Figure 12: DN values for a RADARSAT-2 image at the cursor location (see red box in lower part of figure).

2.2.2.2 Upgrades to the Commercial Satellite Imagery Acquisition Planning System

CSIAPS has undergone a major re-engineering effort to implement a thin-client/server model. SOIN-specific CSIAPS developments are discussed below. Version 2.0 of the CSIAPS data archiving system was provided to SOIN in December 2008 as a major DRDC Ottawa deliverable.

(i) CSIAPS monitor capability. CSIAPS has an archive component that supports both archive-add and archive-search capabilities. The archive-add capability enables the user to add complete images and metadata to the CSIAPS archive. This provides a database population of imagery that may be discovered through the archive-search capability.

In support of SOIN, CSIAPS was modified to move away from a user-based interactive sequence to add images to the archive and towards automated capabilities for performing this task. This modification supports environments where large amounts of data need to be archived and where repetitive tasks by the CSIAPS operator need to be eliminated in order to maximize efficiency.

This automated capability in CSIAPS, which was developed for SOIN, is called the Monitor capability. CSIAPS operators simply need to start the CSIAPS Monitor, then copy images, one-at-a-time, to a specified CSIAPS Monitor folder. As soon as CSIAPS detects an image in this folder, it archives the image and deletes the copy from the folder, in preparation for the next image to be copied to that location. This monitoring capability currently works for RADARSAT-1, RADARSAT-2, and APS product types, as well as other product types.

In support of this capability, an automated product-type detector was implemented in CSIAPS that can examine the product headers and determine what type of product the operator is attempting to archive. The implementation of this capability also required the implementation of the ability for CSIAPS to archive data from a mapped network drive.

(ii) CSIAPS archive photographs. Initially, the CSIAPS archive supported the ability to add and search for remote sensing products from SAR, Electro-Optical or IR sensors. In support of SOIN, capabilities have been added to CSIAPS to enable the CSIAPS operator to add and search for photographs. Types of photographs that may be archived include JPEG photos (geocoded and non-geocoded) and TIFF photos (both geocoded and non-geocoded). When a non-geocoded photo is archived, the CSIAP operator is required to draw a location on the CSIAPS map that represents the geographic location where the photograph was taken.

(iii) CSIAPS viewer. When a user searches the CSIAPS archive, the metadata, the footprint and the browse image may be used to evaluate each search-result. In some cases, the user may wish to interact with the full resolution image, directly from the archive. In support of this, a capability was implemented to enable the CSIAPS operator to open an archived image directly in IA Pro. This operates simply by the operator selecting an ‘open in IA Pro’ icon for a specific search result, then having CSIAPS open IA Pro with the selected image loaded into the viewer. Since CSIAPS operates in a network environment, prior to the IA Pro viewer opening the image, the image has to be copied from the CSIAPS archive to a network location that is accessible by both the CSIAPS server and by the CSIAPS operator’s computer; IA Pro then has to launch on the CSIAPS operator’s computer and open the image from this network location.

2.2.3 Plans for FY 09/10

WP 3.10 will be addressed, amounting to provision of support and upgrades to IA Pro and CSIAPS to better meet SOIN requirements. This will include the implementation of new functionality based upon work carried out within the project, software support and bug fixes, as and when required, and delivery of upgraded versions of the software and documentation.

2.3 WP 4. Ocean features from SAR

2.3.1 Work tasks

The focus of WP 4 is to develop the means to routinely detect the northern wall of the Gulf Stream plus associated eddies and fronts, using spaceborne SAR. WP 4 comprises the following tasks:

WP 4.1 – Develop approach and work plan;

WP 4.2 – Identify and secure auxiliary data sources;

WP 4.3 – Order RADARSAT data;

WP 4.4 – R&D on SST front indicators in SAR that are associated with marine atmospheric boundary layer (MABL) phenomena;

WP 4.5 – Integrate auxiliary surface current data;

WP 4.6 – Conduct field trial.

DFO/BIO has assumed responsibility for the execution of this work package, and will carry out the following activities. For the SAR Meteorological Features Component, the support to SOIN will include, but not be limited to the following:

(i) Document events that denote proxy indicators for the Gulf Stream boundary, such as transitions of rolls to cells, etc. in association with the Gulf Stream and available in-situ measurements.

(ii) Improve edge detection methods for detecting thermal fronts from SAR imagery, based on computer image processing techniques and validated by SST images. Optimize feature detection methods, through studies of clutter to signal, etc.

(iii) Test that proxy indicators for the Gulf Stream boundary, such as transitions of rolls to cells, etc. can be validated by in-situ measured ΔT ; water temperature can be replaced by remotely sensed SST when no *in-situ* data are available. If available, ship and buoy measurements are required for validation.

(iv) Using case studies, demonstrate the validity of new algorithms and methods for locating the thermal front and Gulf Stream boundary from SAR images in automated analysis of the proxy indicators for the Gulf Stream boundary.

(v) It has been proposed that HH polarization SAR is good at monitoring ocean features and VV is good at monitoring atmospheric features, use comparisons of both polarimetric images to discriminate oceanic thermal fronts from atmospheric fronts. Algorithms need to filter atmospheric features out. The method is applicable for dual-pol SAR sensors, Envisat ASAR and RADARSAT-2.

(vi) IA Pro will be implemented at BIO and used in analysis of SAR images, in conjunction with fine-resolution SST maps produced by MetOc Halifax.

(vii) In preparation for July 2008 field program, an auto-scripting routine for automated downloading of ISTOP RADARSAT data at BIO will be implemented, and ghost archiving of specific SAR images will be done.

For the SAR Ocean Features Component, the support to SOIN will include, but not be limited to the following:

(i) Use IA Pro, as provided by DRDC Ottawa, to conduct satellite and auxiliary data blending and co-viewing. If problems arise, advise DRDC Ottawa in writing on a monthly basis:

- Focus on waters off south-western Nova Scotia, the mouth of the Bay of Fundy and in the vicinity of George’s Bank;
- Initiate data collection in June-August 2008 and continue through to March 2009;
- Augment ISTOP RADARSAT imagery provided by the Canadian Ice Service, via the SOIN project, with RADARSAT imagery provided by DRDC Ottawa;
- Obtain available surface air temperature data from public Web sites;
- Obtain required georeferenced synoptic sea-surface temperature (SST), SST composite (MC and LPC) and SST frontal gradient products from the SOIN project;
- Obtain required georeferenced synoptic surface current data from the JRCC/MetOc Halifax CODAR HF radar central processor;
- Utilize surface wind field products generated by DRDC Ottawa from the acquired RADARSAT data;
- Utilize bathymetric contour data products provided by DRDC Ottawa;
- If available through the SOIN project, utilize cloud and true colour synoptic products derived from spaceborne multispectral sensors such as MODIS.

(ii) Use imagery, data products and software tools identified in requirement 1 to:

- Detect features in the RADARSAT imagery that co-locate with thermal features detected in the SST products;

- Investigate the hypothesis that there is a threshold in the magnitude of the surface thermal gradient at SST fronts, below which RADARSAT does not detect the ocean feature;
- Investigate the suggestion that there is a directional bias in RADARSAT's ability to detect ocean features resulting from wave-current interactions.

2.3.2 Progress in FY 08/09

WP 4.1 Status: completed

WP 4.2 Status: completed

Several sources of thermal gradients were investigated, including a commercial software program from WIMSOFT that contained an edge detection algorithm. The edge detection algorithm was evaluated by IML and reported on under WP 2.6. There is also a capability to generate thermal gradients that has been implemented in IA Pro. CODAR surface current data for the Gulf of Maine and SW Nova Scotia remains available to the SOIN project for analysis and assistance with interpretation of SAR imagery.

WP 4.3 Status: in progress

The focus of this project is the waters off south-western Nova Scotia, the mouth of the Bay of Fundy and in the vicinity of Georges Bank. RADARSAT-2 data are being routinely acquired over this area of interest.

WP 4.4 Status: in progress

It was necessary to become proficient in acquiring RADARSAT-1 and RADARSAT-2 SAR data. In preparation for the July 2008 field program, a routine for automated downloading of Integrated Satellite Tracking of Polluters (ISTOP) RADARSAT data (from CIS) at BIO was implemented. The ISTOP data collection at BIO includes the period July 2008 to March 2009, and will continue. With the advent of RADARSAT-2 data, the BIO team also became proficient at ordering this SAR data, and in analysis of SAR data ordered by the SOIN team. The analysis involved geo-referenced synoptic sea-surface temperature (SST), composite (MC and LPC) and frontal gradient products as obtained from the SOIN project, and implementation of IA Pro at BIO, as provided by DRDC Ottawa. This latter software was necessary to conduct satellite SAR and auxiliary data blending, co-viewing and analysis. The SST maps were provided by MetOc Halifax.

BIO activities were initially conceived as consisting of two components: (1) the SAR Meteorological Features Component, and (2) the SAR Oceans Features Component. In actual fact, it became necessary to consider these components together, because the features in the marine boundary layer were strongly coupled to upper ocean features as evident in the SAR images.

In terms of a composite view of both the meteorological and oceanographic features, it is well known [12] that in fair synoptic weather, gradients in SSTs (sea surface temperatures), denoted ∇SST, would be associated with convective marine boundary surface winds, and that downdrafts,

or updrafts, plus air-sea flux modulations would result in modified ocean surface roughness, which would be evident in SAR images.

In SOIN we have documented a set of events where co-locations of SST gradients are clearly evident in SAR images. This is most notable for the Gulf Stream, and processes associated with the Gulf Stream. These are demonstrated in Figure 13 and Figure 14. Gradients in SST are clearly coincident with changes in surface features seen in RADARSAT-2. Some of the processes involved are marine boundary-layer processes in conjunction with the Gulf Stream, such as transitions to rolls and cells, and thus, it is evident that there are clear proxy indicators for the Gulf Stream boundary embedded within this data. But it has been necessary to have accurate SST fields in order to develop the experience to recognize these features, which clearly mark ∇SST.

Detection of ∇SST features depends on determination of surface roughness features in the SAR images that can correlate with the ∇SST. The essential tool to achieve this result was IA Pro, which once implemented at BIO, provided edge detection methods for detecting thermal fronts from SAR imagery, based on computer image processing techniques and validated by SST images. Our studies of clutter to signal, etc. are ongoing but our overall goal was to allow optimization of feature detection methods, through studies of a wide data set of SAR images.

In terms of tests for proxy indicators for the Gulf Stream boundary, features such as transitions of rolls to cells, etc. can be validated by in-situ measured ΔT . Moreover, the clearest evidence for a proxy indicator may well be divergence in wind stress (∇.**u***), or possibly curl of wind stress (∇×**u***) [3]. Thus far, indications from SAR suggest that (∇×**u***) may be a good proxy indicator for ∇SST. Further investigation requires adequate ancillary data, from *in situ* measurements, and MODIS or other remotely sensed SST data. Collaboration with Doug Vandemark at University of New Hampshire and David Long at University of Utah has proven to be essential. This collaboration provided access to high resolution QuikSCAT data for wind speeds and wind directions, at 12.5 km. Although finer-resolution is also possible, the latter data are not deemed reliable enough for the SOIN investigation. Thus, we have made some progress to have the necessary wind directions, allowing high-resolution computation of ∇.**u*** and ∇×**u*** from RADARSAT-2 SAR data, co-locating with ∇SST data. In preliminary case studies we have initial indications that these proxy indicators (**u*,** ∇.**u*** and ∇×**u*)** work for retrieving ∇SST features. These are the potential indicators of entities such as thermal fronts and the Gulf Stream boundary from SAR images.

Whereas RADARSAT-1 data has only HH polarization, RADATSAT-2 allows HH and VV polarization. This permits evaluation of the SAR co-polarization ratio *P*, for monitoring atmospheric features and oceanic thermal fronts:

$$P = \frac{\sigma_o^{VV}}{\sigma_o^{HH}} \tag{1}$$

where σ_o^{VV} and σ_o^{HH} are normalized radar cross section (NRCS) values at VV and HH polarization, respectively expressed in linear units. In terms of polarization ratios, we have used

RADARSAT-2 data to directly compute the SAR co-polarization ratio, *P*. An empirical form for *P* was suggested by Thompson et al. [13] in which the wind speed dependence was ignored, and an incidence angle-dependent model function was fitted to the data of Unal et al. [14] (in linear units):

$$P = \left[\frac{1 + 2\tan^2\theta}{1 + 0.6\tan^2\theta} \right]^2 \tag{2}$$

Other suggested models are from Vachon et al. [16], Elfouhaily [6], and Mouche et al. [11], as shown in Figure 15. Our preliminary empirical formula is of the form:

$$P(\theta) = A\exp(B\theta) + C \tag{3}$$

where *A*, *B* and *C* are empirical constants.

With assistance from DRDC Ottawa, we have gained the ability to compute high-resolution wind stress, **u***, related divergence and curl fields, $\nabla.\mathbf{u^*}$ and $\nabla\times\mathbf{u^*}$, respectively, and the polarization ratio, needed for accurate investigation of RADARSAT-2 data. Evaluation of connections between wind stress products and ∇SST is now possible.

In terms of extending the analysis to all possible RADARSAT-2 images, it has taken some effort to determine specific SAR images where the threshold in the magnitude of surface thermal gradients at SST fronts, is evident. We have not yet been able to quantify the idea of a threshold, below which RADARSAT does not detect ocean features; the methodology is new and we are working to make progress on this question. Probably there is a directional bias in RADARSAT's ability to detect ocean features resulting from dynamical ocean surface features such as waves and surface currents. It is part of ongoing research to quantify these limitations on our abilities.

a) b)

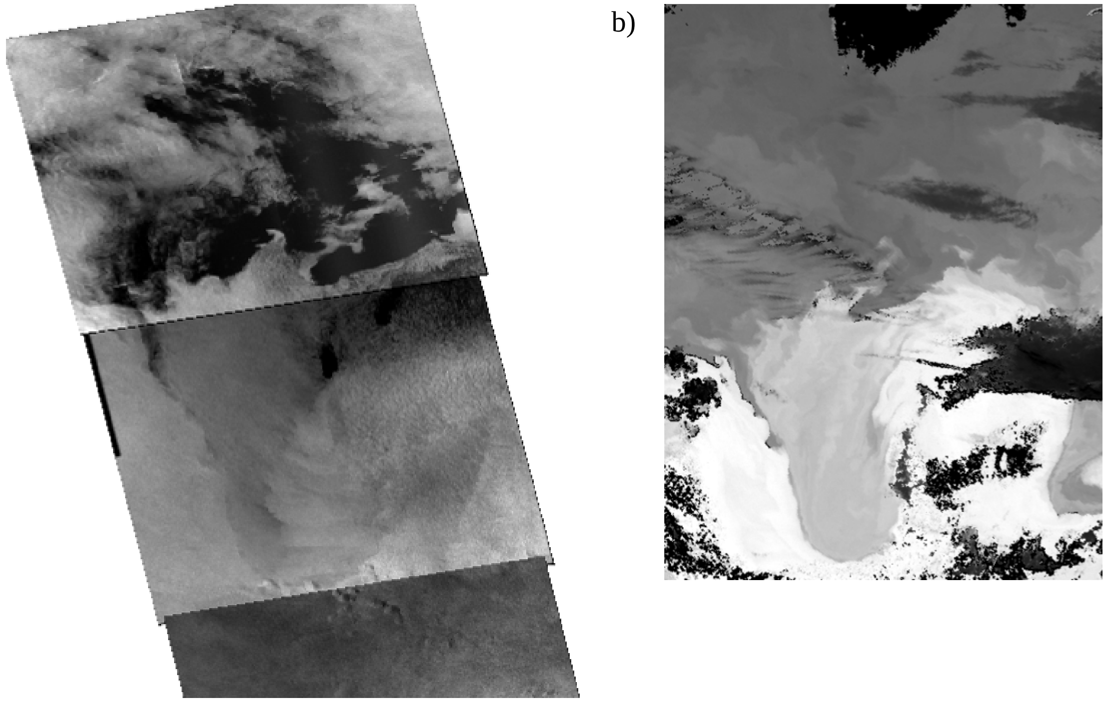

Figure 13: Examples showing (a) RADARSAT-2 SAR image from 4 Nov. 2008, and (b) corresponding near-coincident MODIS image.

a) *b)*

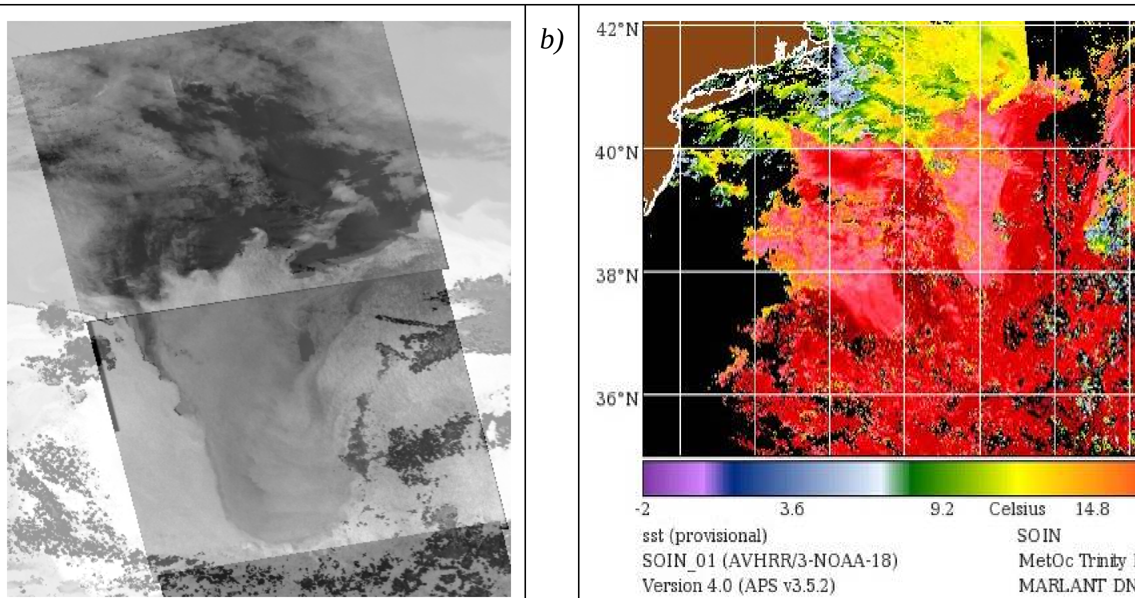

Figure 14: As in previous figure, showing (a) blended SST with SAR, constructed by IA Pro, and (b) SST field from AVHRR for 4 Nov. 2008.

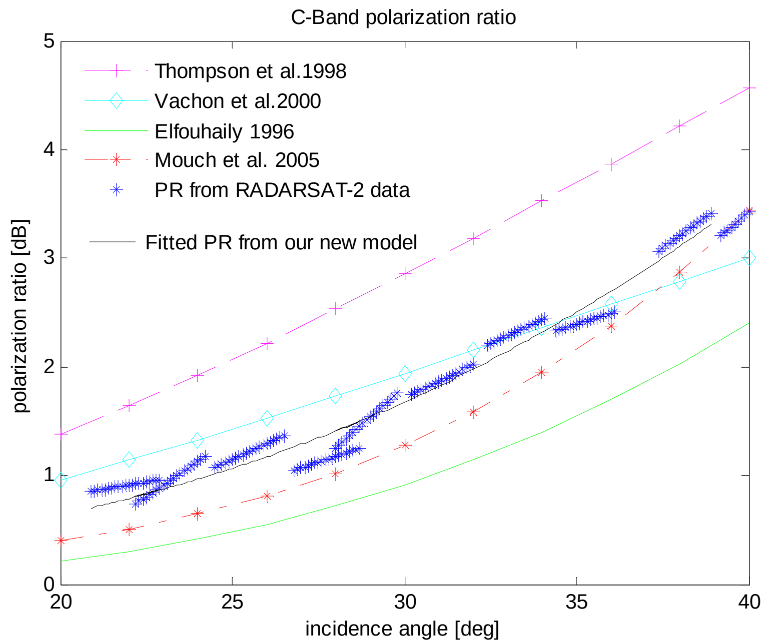

Figure 15: Comparison of models for RADARSAT-1 SAR for the polarization ratio, with our computed estimate (*) based upon direct computations from RADARSAT-2 data.

The following deliverables were completed under this work package:

- Co-incidental and co-located SST images and processed SAR satellite images showing gradients in sea surface temperatures in the area of the Gulf Stream.
- Methodology and related computer codes that show preliminary signs of being able to determine SST gradient processes in SAR images, based on wind stress vector fields, and their divergence and curl fields.
- A manuscript for submission to *Geophysical Research Letters* is in preparation and we hope to submit it within the next couple of months. This paper will document our progress in attaining a qualitative analysis that evaluates the RADARSAT SAR images for detection of the Gulf Stream boundary, as presented in SAR images. Another paper is in preparation on the RADARSAT co-polarization ratio. Other presentations are being planned for the Halifax CMOS congress in late May 2009.

WP 4.5 Status: completed

WP 4.6 Status: in progress

DRDC Atlantic conducted work on two sea trials to collect “ground-truth” oceanographic and atmospheric measurements in support of SOIN WP 4. The first trial was carried out on CFAV QUEST during the period 8-19 September 2008, and had the trial designation Q316. The second trial was carried out on CFAV QUEST during the periods 18-19 January and 19-20 February 2009, and had the trial designation Q320.

(i) Q316

The portion of the trial relevant to SOIN was conducted in the area of the Northeast Channel, between George's and Brown's Bank. The data collection activities included the standard ship-based suite of non-acoustic data acquisition for near surface temperature, air pressure, humidity, wind speed and direction, and bottom depth. Unfortunately, Q316 was not able to deploy a meteorological buoy as initially planned. As a result, the best wind estimates will likely be from the Gulf of Maine Ocean Observing System (GoMOOS) [7] buoy "N" in Northeast channel. Wind estimates derived from RADARSAT-1 and/or RADARSAT-2 satellite imagery can be compared with the GoMOOS meteorological buoy.

There were also ambient noise estimates collected from ocean bottom hydrophones that were moored as part of Q316. Acoustic energy was introduced into the ocean environment using an acoustic projector mounted in an Endeco 850 V-fin tow body, while being towed at a speed of approximately 5 to 6 knots. The moored hydrophones collected the acoustic signals thereby allowing the computation of acoustic transmission loss. The acoustic measurements were conducted on 15 and 16 September. 2008. On 15 September, ship-based wind observations recorded winds in the 20-25 knots range, while on the 16 September, wind speeds of 10-15 knots were recorded.

QUEST also had internet connectivity and as a result was connected to MetOc Halifax, who provided Environment Canada weather products and the MetOc Ocean Feature Analysis (OFA) product. The OFA (Figure 16) represents a near-surface product useful for discriminating the general location of the Gulf Stream northern edge. MetOc Halifax now provides the OFA in network Common Data Form (netCDF) [15], a binary format that is the defacto data exchange standard in the oceanographic community. A software converter was created while on-trial which ingested the OFA into a Geographical Information System (GIS), then allowing comparison with data in the DRDC Atlantic Rapid Environmental Assessment (REA) database [9]. This provided trial personnel with the ability to geo-locate the OFA product with real-time collected data and historical data in the REA database.

Also of relevance to SOIN, was the use of the of numerical ocean model output from both the Canada-Newfoundland Operational Ocean Forecasting System (C-NOOFS) [5] model as supplied by DFO and the French global numerical model known as Mercator [10]. Both models provide vertical temperature and salinity data over 26 vertical levels in the upper 200 m of the water column [5]. Preliminary comparison between model and in situ expendable bathythermograph (XBT) data showed promising results. These models appear to be capable of resolving reasonable vertical structure estimates, thus providing a mechanism for potential joining of the SOIN-based imagery with the ocean vertical structure. The applicability of the model along the northern edge of the Gulf Stream is part of the research being carried out by the international community that makes up the modelling team.

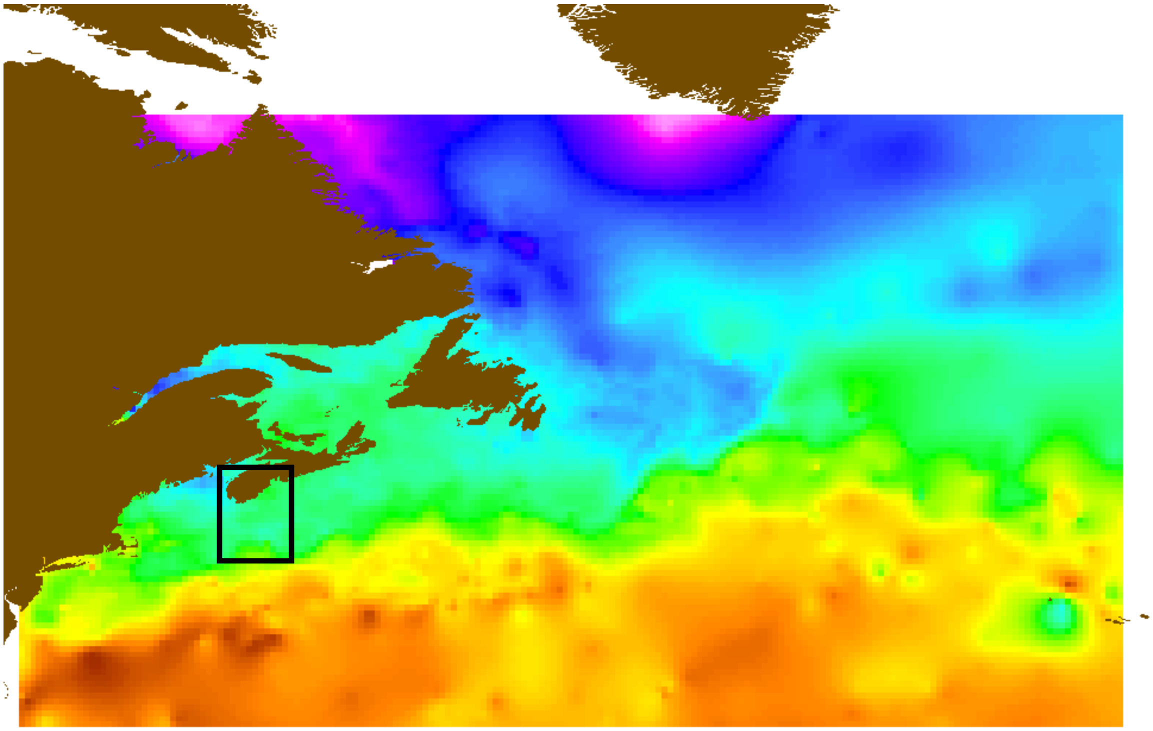

Figure 16: The MetOc Halifax OFA with a continental overlay (brown) displayed in ArcMap™. The temperature range of the figure is 2ºC (white region near Greenland) to 30ºC in the Gulf Stream. The approximate operation area of Q316 is shown by the black box (from [7]).

(ii) Q320

During transits to and from experiments at the Atlantic Undersea Test and Evaluation Center (AUTEC) in January and February 2009, CFAV QUEST conducted measurements in support of SOIN while passing through the Gulf Stream and on the Scotian Shelf. In addition to the standard ship-based suite of meteorological and oceanographic sensors, CFAV QUEST deployed XBTs, self-locating datum marker buoys (SLDMBs), and recorded directional wave spectra using the ship radar based Wave and Surface Current Monitoring System (WaMoS).

The XBTs were launched at a rate of one per hour for a twenty-four period as the ship advanced at a speed of approximately 10 knots. This results in a spacing of approximately 18.5 km between XBTs and a transect length of approximately 450 km. The objective was to collect in situ measurements to enable a comparison of the actual position of the NorthWall of the Gulf Stream (NWGS) with the position resulting from the analysis of RADARSAT-2 satellite imagery. The centre point for the transect was selected on the basis of the anticipated point of intersection of CFAV QUEST with the NWGS according to the most recent OFA (Figure 17).

A preliminary examination of the XBT measurements reveals (Figure 18) that a sharp and near-vertical boundary for the north wall of the Gulf Stream was encountered on 20 February 2009 between XBT 89 (14:21 UTC, 37º55.175N, 068º26.691W) and XBT 90 (15:22 UTC, 38º 05.458N, 068º18.482W). RADARSAT-2 imagery of this area was collected on the previous day, 19 February, during a descending pass at approximately 10:35 UTC as well as on the following

day, 21 February, during an ascending pass at approximately 22:34 UTC (Figure 17). A similar temperature cross-section for the southern transit (not shown) also shows clear evidence for crossing the Gulf Stream, though the contrast in surface water temperatures is not as pronounced.

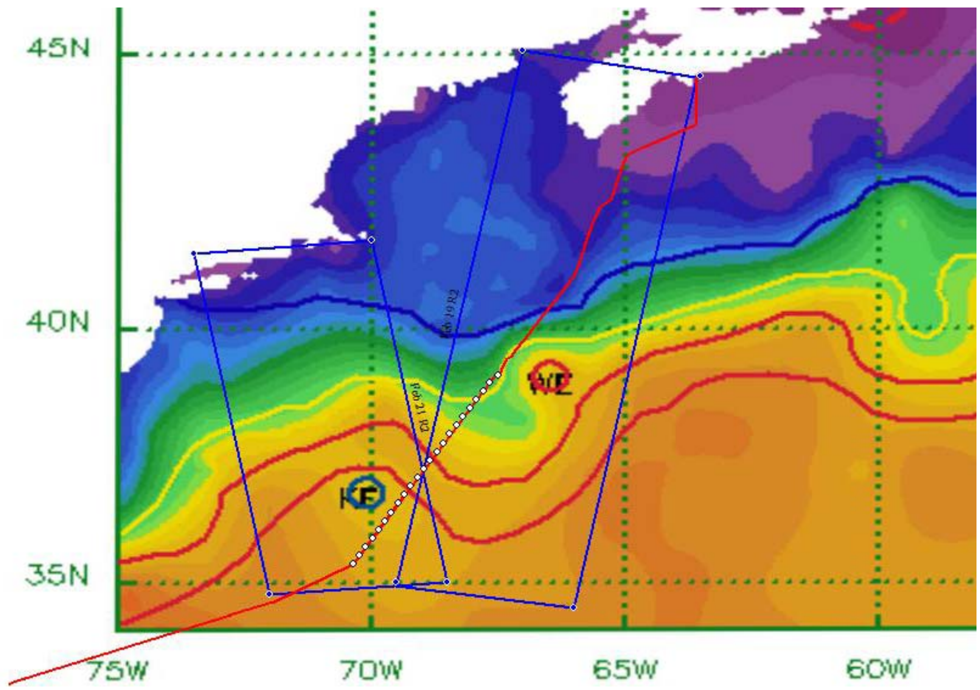

Figure 17: Track of CFAV Quest on 19 and 20 February 2009 superimposed on a MetOc Halifax OFA valid for 13 to 17 February 2009.
The white dots along the ship track represent the locations at which XBTs were launched. The blue boxes represent the approximate location of RADARSAT-2 coverage on 19 February (northeast to southwest strip) and 21 February (southeast to northwest strip).

SLDMBs are used to make in situ measurements of surface currents, primarily as an operational tool for Search and Rescue missions. Typically, a cluster of 3 to 5 SLDMBs is deployed at a reported last known position, or another relevant location. The SLDMBs report their positions via the ARGOS satellite, from which drift rates due to surface currents and/or winds can be determined, with search patterns modified accordingly.

For the SOIN work on Q320, the SLDMBs were configured in ‘Person In The Water’ mode, such that they move predominately under the influence of surface currents rather than wind. Three clusters were deployed during the southward transit of CFAV QUEST on 17 and 18 January, two on the Scotian Shelf (43º44.85N, 063º29.86) and (42º01.82N, 064º25.51) and one north of the north wall of the Gulf Stream (39º10.02N, 067º05.10). Two clusters were deployed on 21 February during the northward transit of CFAV QUEST, both on the Scotian Shelf at (42º30.00N, 065º20.41) and (43º56.67N, 063º53.75). The northern SLDMB deployment positions on the Scotian Shelf are well within the domain of the DALCOAST III ocean circulation model [4], to enable a comparison of a ‘particle trajectory’ capability with in situ measurements. The southern

SLDMB positions on the Scotian Shelf are towards the southern edge of the domain of the DALCOAST III model, so a comparison may or may not be possible. The drift pattern of the SLDMB cluster deployed north of the Gulf Stream is outside of the DALCOAST III model domain so a comparison will have to be made with an ocean circulation model with a larger domain (and coarser resolution).

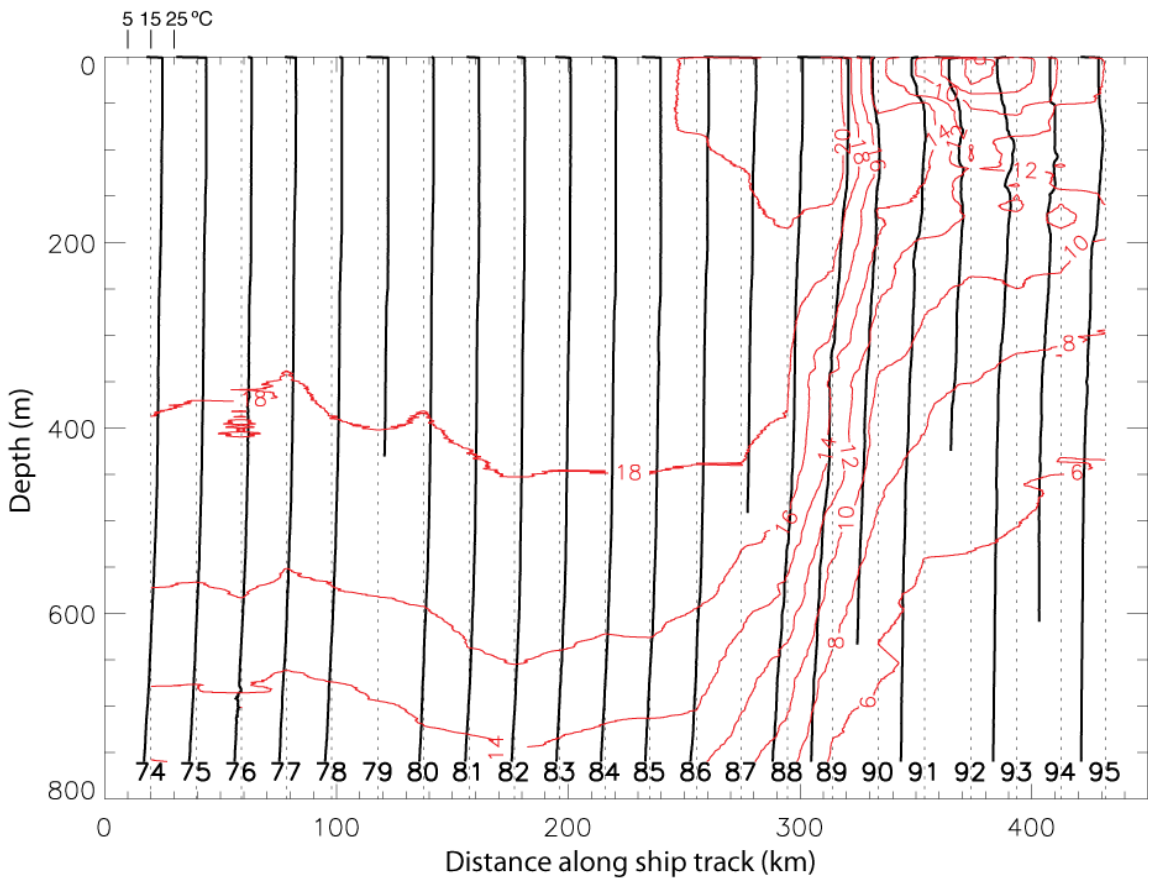

Figure 18: Compilation of XBT profiles collected during the northern transit of CFAV QUEST through the Gulf Stream on 19 and 20 February 2009.
Vertical dashed black lines represent XBT launch positions with the respective XBT identification numbers at the base of each profile. The vertical dashed black lines also serve as a reference temperature of 15 ºC for the XBT temperature profiles (the solid black lines). Red lines are contours of temperature in increments of 2ºC. The abrupt change in water temperature between XBTs 89 and 90 reveals the position of the north wall of the Gulf Stream.

2.3.3 Plans for FY 09/10

The following activities are planned for FY 09/10:

- Analyze the data from the CFAV QUEST trials conducted by DRDC Atlantic.

- Focus on SAR images that cross the north wall of the Gulf Stream where SST gradients occur, co-located with high-quality images of remotely sensed SST as processed by MetOc Halifax. Archive a large set of these images.
- Analyse the wind field, wind stress fields, and their curl and divergence and search for correlations with temperature gradients.
- Use high-resolution scatterometer winds co-located with SAR images, in collaboration with University New Hampshire, to do SAR-wind analysis
- Use empirical relations between, for example curl wind stress and temperature gradient to get methodology for determination of SST features in SAR images.
- Using case studies, demonstrate the validity of new algorithm for retrieving the thermal front and Gulf Stream boundary from SAR images in automated analysis of the proxy indicators for the Gulf Stream boundary.
- Use IA Pro for co-location studies of, for example curl wind stress and temperature gradient to verify methodology and algorithm
- Focus on waters off south-western Nova Scotia, the mouth of the Bay of Fundy and in the vicinity of George's Bank.

2.4 WP 5. SOIN compatible ocean workstation

2.4.1 Work tasks

The purpose of WP 5 is to integrate MetOc Halifax's existing Ocean Workstation (OWS) with SOIN related data outputs. Previously, the OWS ingested manually-downloaded AVHRR SST data, which was very time consuming and relied upon outside agencies. With the completion of WP 5.1, MetOc Halifax can ingest APS generated SST output directly into the OWS. Combined with other in-situ oceanographic data from ships, buoys, and ARGOS drifters, oceanographic fronts and watermass boundaries can be delineated and provide to the fleet for operational planning purposes. Follow on work will include further development of the OWS to integrate ocean features detected in SAR imagery by IA Pro.

WP 5.1 – Integrate MetOc Halifax auxiliary data from APS into the OWS;

WP 5.2 – Integrate APS and SAR processor;

WP 5.3 – Staff training.

2.4.2 Progress in FY 08/09

WP 5.1 Status: completed

JASCO Research Ltd. completed this work under contract which involved making the existing ocean workstation at MetOc Halifax able to ingest APS SST output. MetOc Halifax ocean personnel now use this capability in the bi-weekly production of the Ocean Features Analysis

chart, which has enhanced their productivity and reduced MetOc Halifax reliance on third party data sources. The work also involved conducting a comprehensive analysis of the existing OWS system and software application.

2.4.3 Plans for FY 09/10

WP 5.2 and 5.3 are planned to be initiated and completed.

2.5 WP 6. Phase II Go/No Go workshop

Work on this WP will commence in FY 09/10. The workshop will be held in early December 2009, with the proposal forwarded in January 2010 to the CSA for a decision. Phase II will concentrate on operationalizing the use of SOIN-SAR within MetOc Halifax and the operational delivery of SOIN products to other government departments such as CIS and JRCC. It will also initiate the development of second generation ocean features from SAR product and investigate the utilization of ocean models in SOIN processes.

2.6 WP 7. RMC SAR ocean imaging model

2.6.1 Work tasks

The concept for this new WP arose from work on maritime mapping with SAR that was done at DRDC Ottawa [17]. An outcome of this work was a recommendation that a SAR ocean imaging model should be developed in support of CF operations. Such an initiative would be directly relevant to SOIN objectives. Discussion ensued with Prof. Joseph Buckley, Physics Department, RMC on establishing a R&D program to meet these objectives. This concept was subsequently proposed to CSA, who agreed to fund a new WP in this area. The WP, which should commence in FY 2010/2011, has been broken down as follows:

WP 7.1 – Work Package Management:

- Hire personnel (Postdoctoral Fellow, MSc students);
- Develop working procedures and plan;
- Report on model status at bi-annual SOIN review meetings;

WP 7.2 – Conduct survey of existing SAR models:

- Assess merits of each model in the context of the requirements of the Canadian user community and for RADARSAT-2 sensor;
- Present findings to SOIN project management team along with recommendation on which model to acquire;

WP 7.3 – Acquire agreed-to SAR model;

WP 7.4 – Install, modify and validate forward model:

- Rebuild model to run on RMC computing facilities;
- Modify model to run using inputs from MetOc IA Pro system and its successors for imaging parameters appropriate for RADARSAT-2 beam geometries;
- Validate model with field data and RADARSAT-2 imagery;

WP 7.5 – Develop and validate inverse model:

- Investigate inversion feasibility and methodology;
- Recommend to SOIN PM team on inversion feasibility:
    - If feasible, code inverse model to run on RMC computing facilities using IA Pro inputs;
    - If the inverse model is implemented, validate with field data and RADARSAT-2 imagery.

WP 7.6 – Integrate model into IA Pro and its successors:

- Explore feasibility and methodology for integration of the model into IA Pro;
- Recommend to SOIN project management team on integration feasibility and technique.

2.6.2 Progress in FY 08/09

The SAR ocean imaging model WP was proposed to CSA/GRIP early in the FY, but due to funding limitations, it was decided to delay kick-off of this WP until Phase II of the project.

2.6.3 Plans for FY 09/10

This WP will be delayed until Phase II, FY 10/11. Further definition and refinement of the plan will be completed. RMC is hoping to initiate some activities with their own funding.

2.7 WP 8. Statistical analysis of SAR data

2.7.1 Work tasks

The purpose of WP 8 is to provide the SOIN project with a statistical analysis capability to assist in the development of a methodology to study ocean fronts and eddies from SAR imagery.

WP 8.1 – Conduct a study of the North Wall of the Gulf Stream (NWGS) to capture its statistical properties, to include:

- Selection of an appropriate SST data set and collection of chosen data;
- Development of an algorithm that can identify the NWGS in the SST images; and
- Capture the statistical properties of the shape and location of the NWGS.

WP 8.2 – Develop an algorithm as an “add-on" package to IA Pro that allows the user to:

- Select an identified edge in RADARSAT imagery;
- Initiate an algorithm that computes the probability that the selected edge is an oceanographic feature such as the NWGS or any other prominent feature such as a warm-core ring, eddy, boundary or thermal/dynamic front.

WP 8.3 – Develop a “shape and location based" algorithm that can identify portions of the NWGS, along with warm-core ring, eddy, boundary or thermal/dynamic fronts.

WP 8.4 – Test all algorithms on a set of SAR images to gauge their effectiveness.

2.7.2 Progress in FY 08/09:

WP 8.1 Status: completed

A front-finding algorithm was developed based upon the histogram analysis of Cayula and Cornillion [2] and applied to HYbrid Coordinate Ocean Model (HYCOM) [8] SST data in an attempt to identify the regions in which the NWGS is likely to be found. After the SOIN meeting in December 2008 it was noted that the front identification algorithm used with the HYCOM SST data does not capture the Gulf Stream proper but rather only certain features such as the on-shelf temperature front, which occurs in the region of the NWGS but is itself not an indication of the location of the NWGS. Some effort was expended on improving the front identification algorithm, but it was realized that the SST data is simply not sufficient for the identification of the NWGS. The SST of the Gulf Stream is not distinguishable from surrounding warm water near the tropics and there is a temperature gradient in the Gulf Stream itself as it flows northward. These features mean that a histogram analysis of the SST cannot separate the Gulf Steam from surrounding waters in the tropics and cannot identify the entire body of the Gulf Steam as a single unit, which led to the use of sea-surface height.

WP 8.2 Status: completed

There is a very well defined boundary between regions of positive and negative anomalies in Sea Surface Height (SSH) images. This boundary, which is easily captured by the front-finding algorithm, is associated with the path of the Gulf Stream, as shown in Figure 19. It may be assumed that this boundary is a good estimate of the location of the NWGS. A total of 1836 HYCOM SSH images, occurring at a frequency of one per day, were subject to the improved front-finding algorithm to produce (1) a region map and (2) a front. The fronts for all 1836 images were combined to form a two-dimensional histogram. This histogram provides some essential information about the NWGS: (1) the NWGS is composed of a stable portion occurring over the first half of its trajectory and an unstable portion occurring just south of the Scotian Shelf, (2) there is a fairly well defined northern boundary of the unstable region. The collection of region maps may be subject to empirical orthogonal function (EOF) analysis. In the first EOF there is a path along which the EOF is zero. This represents the node of the EOF, which may be interpreted to be the dominant or climatic trajectory of the NWGS. We may define a search region, a region in which we can expect to find the NWGS as follows: the southern boundary is the node of the first EOF of the region maps; the northern boundary is the northern edge of the front histogram.

With this search region defined it is possible to construct a probabilistic model to answer the second question of interest, namely: What is the probability that an edge feature identified in a RADARSAT image that occurs in the search region is a signature of the NWGS?

The two models implemented were a simple model, and logistic regression. The simple model requires approximately 15 SAR/SST pair images, as shown in Figure 20. It is expected that this number of feature pairs is obtainable from the RADARSAT data collected since September 2008.

WP 8.3 Status: completed

Features that are roughly circular or are a portion of a circle are fairly straightforward to identify. Since cold-core rings form on the north side of the NWGS, a search region for rings easily stems from the NWGS identification algorithm: define a ring criteria; collect a set of SAR/SST feature pairs that occur within the search area for rings that satisfy the ring criteria; estimate the probability that an identified ring feature is the signature of a cold-core ring; as data accumulates, build a logistic model for ring identification.

WP 8.4 Status: in progress

2.7.3 Plans for FY 09/10

In FY 09/10, effort will focus on completing WP 8.4. For the simple model in WP 8.2, about 15 SST/SAR image pairs are needed. The difficulty with the more advanced logistic regression method is that a larger number of data points are required to estimate the coefficients, as shown in Figure 21. As a rough estimate, 60 SAR/SST data pairs are required to fit a logistic model with three of four predictor variables. Given the degree of cloud contamination typical in SST images, it may be difficult to gather this amount of data. A reasonable way forward is to start with the simple approach, estimating a single probability for the search region and then, as data is accumulated, build a logistic model.

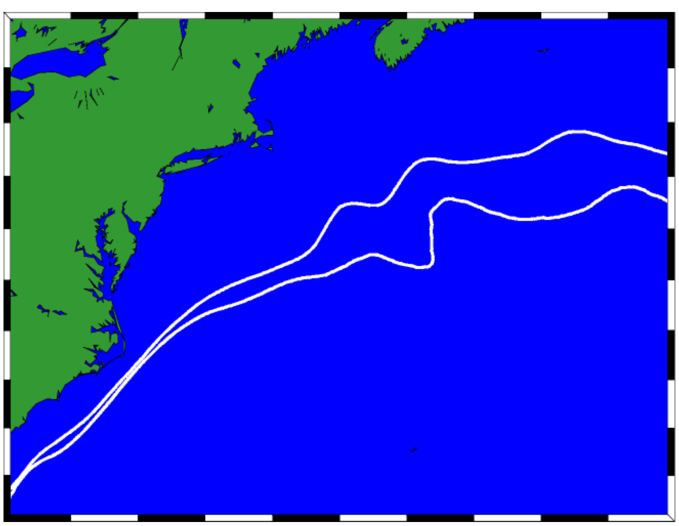

Figure 19: The proposed search region for the NWGS. The limits are the northern extent of the SSH boundary and the node of the first EOF of the set of regional maps.

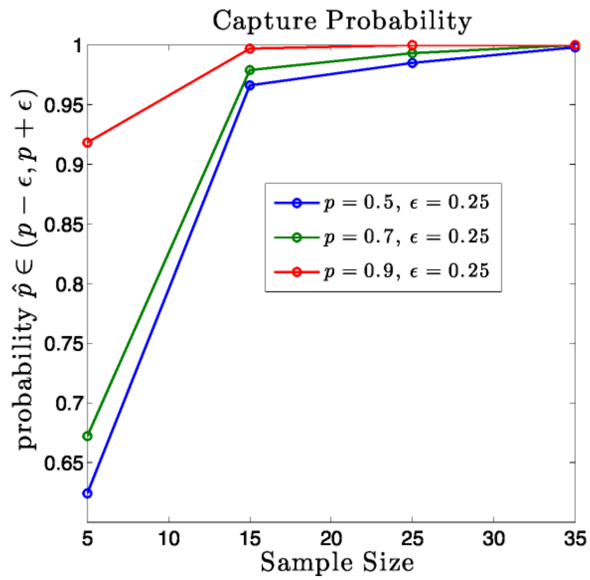

Figure 20: A computer simulation was conducted to estimate the number of SAR/SST feature pairs n required to estimate p with 0.25 of the true value with a probability of ≥ 90%.

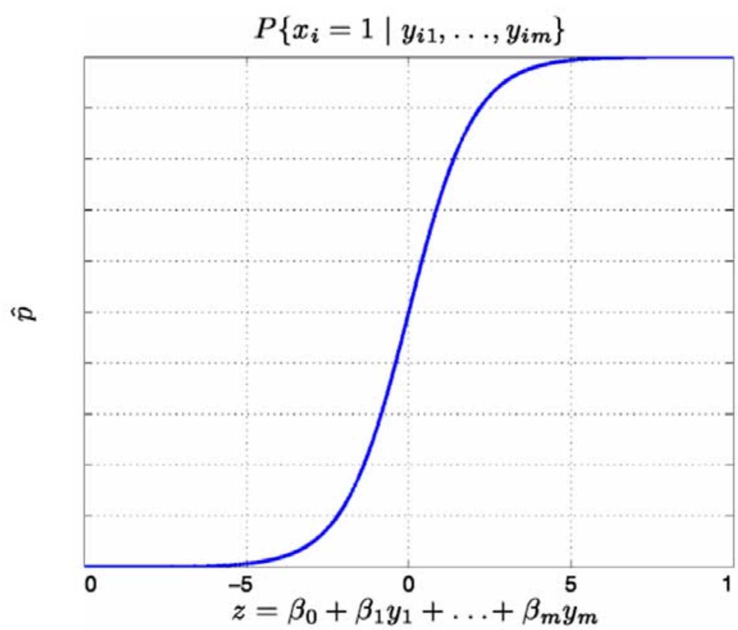

Figure 21: Logistic regression provides a means of determining to which of two categories an object belongs as a function of a composite predictor variable.

3 Summary

SOIN is a five-year research and operational development initiative that addresses barriers to implementing certain oceanographic applications of the Earth-observation sensors RADARSAT, AVHRR, MERIS and MODIS. The project is divided into two phases with the first three-year phase focusing on developing state-of-the-art sea-surface temperature and diver-visibility products, operational tools, supporting infrastructure and the ability to detect thermal fronts, eddies and water mass boundaries with RADARSAT. Lead by MetOc Halifax, SOIN was launched in June 2007 with funding provided by CSA through GRIP. This report provides a summary of project activities and accomplishments in FY 08/09 and insight into its objectives for FY 09/10.

Three fundamental barriers that SOIN must address in order to achieve its operational objectives are: (i) a lack of required infrastructure; (ii) insufficient auxiliary data provided in required time frames, spatial scales and file formats; and (iii) insufficient knowledge of how to interpret synthetic aperture radar (SAR) imagery for operational ocean feature applications.

In addition to work pertaining to project management (WP 1), SOIN initiated two new work packages in FY 08/09. Namely, WP 5 (SOIN compatible Ocean Workstation), and WP 8 (statistical analysis of SAR data). WP 2 has experienced some delays due to factors beyond the project's control. WP 3 is now largely complete with the only changes are those that will arise out of further research from WP 4 and 8. Another notable development during the FY has been the initiation of regular, ongoing ordering, collection, and distribution of RADARSAT-2 data amongst the SOIN partners. This has resulted in close cooperation with the CIS and CSA order desks to deconflict swath coverage. The project also received approval to share RADARSAT-2 data from the SOIN region (Gulf of Maine and south-western Scotian Shelf) with the University of Maine and University of New Hampshire. The field program included cruises by CFAV QUEST in September 2009 and January 2009 for DRDC Atlantic related research and provided in-situ data for the analysis of coincident SAR imagery over part of the SOIN area.

In FY 09/10 SOIN will continue to develop and expand these systems, including integrating MERIS and the MODIS X-band antenna data into APS. Additional focus will be placed on WP 4, 5, and 8. WP 6 will be initiated later in the FY. There will be a significant presence of the SOIN project at the CMOS Congress being held in Halifax May 31 – June 4, with four scheduled talks dealing with research and results from the project so far.

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Annex A GRIP – Proposal summary tables

Work Packages commenced in FY 08/09:

Id WP 5.0:

Title:	**SOIN-compatible Ocean Workstation**
Purpose:	To initiate development of SOIN-compatible MetOc ocean workstation (OWS).
Work tasks:	5.1 – Integrate MetOc Halifax auxiliary data; 5.2 – Integrate APS and SAR processor; 5.3 – Staff Training.
Expected results:	Version 1.0 of SOIN ocean workstation (integrates APS, SAR processor + auxiliary data sets).

Id WP 8.0:

Title:	**Statistical Analysis of SAR data**
Purpose:	To develop a statistical analysis capability to assist in the development of a methodology to study ocean fronts and eddies from SAR imagery.
Work tasks:	8.1 – Conduct a study of the North Wall of the Gulf Stream (NWGS) to capture its statistical properties; 8.2 – Develop an algorithm as an “add-on" package to IA Pro that allows the user to select an identified edge in RADARSAT imagery; 8.3 – Develop a “shape and location based" algorithm that can identify portions of the NWGS, along with warm-core ring, eddy, boundary or thermal/dynamic fronts; 8.4 – Test all algorithms on a set of SAR images to gauge their effectiveness.
Expected results:	Algorithms and models of locations of the Gulf Stream and eddies to assist in the detection of these features in SAR images.

Work Packages proposed for Phase II (FY 10/11 – 11/12)

Id WP 7.0:

Title:	**SAR Ocean Imaging Model**
Purpose:	To develop a Canadian SAR imaging model for ocean features. The interaction of the sea surface with electromagnetic radiation of the frequencies, polarizations and incidence angles appropriate to spaceborne SAR sensors, in particular to RADARSAT-2 is then modeled, resulting in a predicted SAR image for the specific sea surface conditions.

Work tasks:	7.1 – Work Package Management:
	• hire personnel (Postdoctoral Fellow, MSc students);
	• develop working procedures and plan;
	• report on model status at bi-annual SOIN review meetings;
	7.2 – Conduct survey of existing SAR models:
	• assess merits of each model in the context of the requirements of the Canadian user community and for RADARSAT-2 sensor;
	• present findings to SOIN Team along with recommendation on which model to acquire;
	7.3 – Acquire agreed-to SAR model;
	7.4 – Install, modify and validate forward model:
	• rebuild model to run on RMC computing facilities;
	• modify model to run using inputs from MetOc IA Pro system and its successors for imaging parameters appropriate for RADARSAT-2 beam geometries;
	• validate model with field data and RADASRAT-2 imagery
	7.5 – Develop and validate inverse model:
	• investigate inversion feasibility and methodology;
	• recommend to SOIN Team on inversion feasibility:
	    o if feasible, code inverse model to run on RMC computing facilities using IA Pro inputs;
	    o if the inverse model is implemented, validate with field data and RADARSAT-2 imagery;
	7.6 – Integrate model into IA Pro and it successors:
	• explore feasibility and methodology for integration of the model into IA Pro;
	• recommend to SOIN Team on integration feasibility and techniques.

Expected results:	The predicted SAR image will be validated against images collected simultaneously from the SAR sensors. Many validations will be required under significantly different circumstances to gain confidence in the model. Once the model is validated, it will be inserted as an imaging tool into the SOIN operational suite.

Annex B GRIP – Quad sheet

Canadian Space Agency | Agence spatiale canadienne

Government Related Initiatives Program – Project Overview

Project Title: Spaceborne Ocean Intelligence Network (SOIN) **Status: Entering Phase I, Year 3 of 3**
Lead Depart.: Department of National Defence [MetOc Halifax]
Keywords: maritime security, meteorology, oceanography, search and rescue, RADARSAT, AVHRR, MODIS, MERIS

Concept:

- Meteorology & oceanography (METOC) operations are overwhelmed with environmental information of civilian origin that they cannot use because: (i) it is not provided in operationally-compatible time frames and formats; and (ii) there are insufficient means to automate the product generation process;
- SOIN will address these barriers to operational use by: (i) developing image analysis, image processing and auxiliary data integration tools that produce METOC products in required formats; and (ii) integrating these tools and resulting products into existing and planned operations of MetOc Halifax, the Canadian Ice Service and the Joint Rescue Coordination Centre Halifax.

Objectives:

- To advance Canada's ability to produce operational METOC products for maritime defence and civilian security-related operations;
- To research & develop operational means to monitor mesoscale coastal & oceanic fronts and eddies with spaceborne SAR;
- To provide MetOc Halifax with the operational tools & infrastructure required to achieve these goals and to distribute resulting products to other agencies.

Description and Technical Approach:

- MetOc Halifax has established two technical teams – one that focuses on products based on thermal IR and multispectral imagery, the other on SAR;
- In the 2nd and 3rd years of the project, products produced by both teams will be integrated by a new METOC ocean workstation.

Results To Date:

- Thermal IR / multispectral APS system installed at MetOc Halifax;
- SAR Processor V.1 (within IA Pro) installed at MetOc Halifax;
- Initial modifications to IA Pro completed;
- Coastal & ocean fronts / eddies from SAR R&D initiated.

Partners:

- DND [DRDC Ottawa, DRDC Atlantic];
- EC [Canadian Ice Service];
- DFO [Maurice Lamontagne Institute, Bedford Institute of Oceanography, Joint Rescue Coordination Centre (JRCC) Halifax – joint CCG and CF];
- US Navy [Naval Research Laboratory - NASA Stennis Space Flight Center];
- Academic [Dalhousie University, Royal Military College, University of New Hampshire, University of Maine].

Budget:

GRIP:	$1,356,850 (29%)
Lead Dept.:	$1,986,275 (43%)
Partner(s):	$1,254,819 (28%)
Total	$4,597.944

Schedule:

Phase I Start:	FY 2007/08
Phase I End:	FY 2009/10
Phase II Start:	FY 2010/11
Phase II End:	FY 2011/12

Outputs for 2008-2009:

- APS compatible OWS at MetOc Halifax;
- Further improvements to IA Pro;
- Coastal & ocean fronts / eddies from SAR R&D continued;
- Extensive collection and dissemination of RADARSAT-2 data among project partners.
- Phase II Go/No Go workshop and decision.

Canada

May 2009

Annex C GRIP – Schedule

	PHASE I												**PHASE II**			
WP	**FY 07/08**				**FY 08/09**				**FY 09/10**				**FY 10/11**		**FY 11/12**	
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List of acronyms

A	Azimuth (SAR along-track direction)
APS	Automated Processing System (NRL Stennis software)
ASAR	Advanced SAR (C-band SAR sensor on ENVISAT)
ASCII	American Standard Code for Information Interchange
AUTEC	Atlantic Undersea Test and Evaluation Center
AVHRR	Advanced Very High Resolution Radiometer (sensor on NOAA’s polar orbiting satellites)
BIO	Bedford Institute of Oceanography (DFO, Halifax, Nova Scotia)
CCRS	Canada Centre for Remote Sensing (Natural Resources Canada)
CF	Canadian Forces
CFAV	Canadian Forces Auxiliary Vessel
CIS	Canadian Ice Service (Environment Canada)
C-NOOFS	Canada-Newfoundland Operational Ocean Forecasting System
CODAR	Coastal Ocean Dynamics Applications Radar (HF radar)
CSA	Canadian Space Agency (Industry Canada)
CSIAPS	Commercial Satellite Imagery Acquisition Planning System (DRDC Ottawa software)
DALCOAST	Dalhousie Coastal model
DFO	Department of Fisheries and Oceans
DN	Digital Number
DND	Department of National Defence
DRDC	Defence Research & Development Canada (agency of DND)
ECR	External Client Report
ENVISAT	Environmental Satellite (European Space Agency Mission)
EOF	Empirical Orthogonal Function
ESA	European Space Agency
FY	Fiscal Year
GoMOOS	Gulf of Maine Ocean Observing System
GRIB	Gridded Binary
GRIP	Government Related Initiatives Program (CSA)
HDF	Hierarchical Data Format

HF	High Frequency
HH	Horizontal transmit, Horizontal receive radar polarization
HYCOM	HYbrid Coordinate Ocean Model
IA Pro	Image Analyst Pro (DRDC Ottawa software)
IML	Institute Maurice Lamontagne (DFO, Mont-Joli, Québec)
IR	Infra-Red
ISTOP	Integrated Satellite Tracking of Polluters (CIS program)
JPEG	Joint Photographic Experts Group (imagery file format)
JRCC	Joint Rescue Coordination Centre (DND and DFO) Halifax
LPC	Latest Pixel Composite
LUT	Look-Up Table
MABL	Marine Atmospheric Boundary Layer
MC	Mean Composite
MERIS	Medium Resolution Imaging Spectrometer (sensor on ESA's ENVISAT satellite)
MetOc	Meteorology and Oceanography
MODIS	Moderate Resolution Imaging Spectroradiometer (sensor on NASA's Terra and Aqua satellites)
NASA	National Aeronautics and Space Administration (USA)
NOAA	National Oceanic and Atmospheric Administration (USA)
NRCS	Normalized Radar Cross Section
NRL	Naval Research Laboratories
NWGS	North Wall of the Gulf Stream
OFA	Ocean Feature Analysis
OWS	Ocean Workstation
QuikSCAT	Refers to the SeaWinds Scatterometer aboard NASA's Quick Scatterometer satellite mission
R	Range (SAR across-track direction)
R&D	Research and Development
REA	Rapid Environmental Assessment
rgb	Red, Green, Blue
SAR	Synthetic Aperture Radar
SCNA	ScanSAR Narrow A (a mode on RADARSAT-1 and RADARSAT-2)

SCNB	ScanSAR Narrow B (a mode on RADARSAT-1 and RADARSAT-2)
SLDMB	Self-Locating Datum Marker Buoy
SOFDT	SAR Ocean Feature Detection Tool (an IA Pro tool)
SOIN	Spaceborne Ocean Intelligence Network
SSH	Sea-Surface Height
SST	Sea-Surface Temperature
TIFF	Tagged Image File Format (imagery file format)
VV	Vertical transmit, Vertical receive radar polarization
WaMoS	Wave and Surface Current Monitoring System
WP	Work Package
XBT	Expendable Bathythermograph

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SOIN is a five-year research and operational development initiative that addresses barriers to implementing certain oceanographic applications of the Earth-observation sensors RADARSAT, AVHRR, MERIS and MODIS. The project is divided into two phases with the first three-year phase focusing on developing state-of-the-art sea-surface temperature and diver-visibility products, operational tools, supporting infrastructure and the ability to detect thermal fronts, eddies and water mass boundaries with RADARSAT. The project began in June 2007 with funding provided by the Canadian Space Agency through its Government Related Initiatives Program. This report provides a summary of project activities and accomplishments in FY 08/09 and insight into its objectives for FY 09/10.

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SOIN; RADARSAT; synthetic aperture radar; SAR; SST; Ocean Features; METOC

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